FINAL REPORT

Stable Isotope Analysis Report

GE Aviation
Evendale, Ohio

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GE Aviation – Evendale, Ohio

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LIST OF ACRONYMS

COPC – compound of potential concern

CF-IRMS – continuous flow-isotope ratio mass spectrometer

CSIA – compound specific isotope analysis

CSM – conceptual site model

CVOC – chlorinated volatile organic compound

$\delta^{13}C$ – delta ^{13}C [‰], carbon stable isotope ratio, in parts per thousand, or per mil

$\delta^{37}Cl$ – delta ^{37}Cl [‰], chlorine stable isotope ratio, in parts per thousand, or per mil

DCA - dichloroethane

DCE – dichloroethene

DE - *Dehalococcoides ethanogenes*

EIL – Environmental Isotope Laboratory, University of Waterloo, Canada

GC – gas chromatograph

IM, IRM – Interim Measures, Interim Remedial Measures

LSG – lower sand and gravel

MDL – method detection limit

MNA – monitored natural attenuation

ORP – oxidation-reduction potential

QA/QC – quality assurance/quality control

QL – quantitation limit

SIL – Stable Isotope Laboratory, University of Toronto, Canada

SPME – solid phase micro extraction

TCA - trichloroethane

TCE - trichloroethene

TEA (or TEAP) - terminal electron acceptor (process)

USAF – United States Air Force

USEPA – United States Environmental Protection Agency

USG – upper sand and gravel

VC – vinyl chloride

VOC – volatile organic compound

V-PDB – Vienna-PeeDee Belemnite reference standard for carbon isotopes

V-SMOW – Vienna-Standard Mean Ocean Water reference standard for chlorine isotopes

1. INTRODUCTION

The General Electric Aviation (GE) facility in Evendale, Ohio has undertaken a Corrective Action Program to evaluate the nature and extent of releases from solid waste management units (SWMUs) and Areas of Concern (AOCs) at the GE site (Figure 1). As part of this program, compounds of potential concern (COPCs) were identified in groundwater along the southern perimeter of the property. The available information suggests that sources of these COPCs are located on-site; in particular, the former US Air Force (USAF) Plant No.36 (AFP 36), which comprises the southern portion of the GE property. Additional sources may exist beyond the boundary of AFP 36. These additional sources may contribute to the extent of the groundwater plume currently being addressed by GE under RCRA Interim Measures (IM) activities. GE is currently implementing a hydraulic control Interim Remedial Measure (IRM), consisting of a groundwater extraction well network and ex-situ groundwater treatment system, to address COPCs along the southern perimeter of the property.

Compound specific isotope analysis (CSIA) was performed in July 2008 and November 2009 to support further development of the Conceptual Site Model (CSM) and to better understand biodegradation and chemical migration pathways between impacted areas. This report documents the methods and results of CSIA of groundwater samples collected in July 2008 and November 2009 at the GE facility.

1.1 BACKGROUND

Several previous investigations have been performed to characterize the nature and extent of impact to soil and groundwater at AFP 36 and the immediately surrounding area (Site). These investigations provide the following basic level of understanding of Site conditions (O'Brien & Gere, 2008a; 2009):

- The stratigraphy underlying the Site consists of five major sedimentary facies:
  - Perched aquifer – groundwater flow is south-southeast
  - Upper Confining Layer (discontinuous silt and clay unit)
  - Upper Sand and Gravel (USG) aquifer – groundwater flow predominately southwest with a southeast component
  - Lower Confining Layer (discontinuous silt and clay unit)
  - Lower Sand and Gravel (LSG) aquifer – groundwater flow is south-southwest
- The Perched and USG aquifers are hydraulically connected on the eastern side of AFP 36 and immediately to the southeast. The USG aquifer is also hydraulically connected to the LSG aquifer along the southern and southwestern side of AFP 36. The extent and thickness of the upper and lower confining layers and the general extent of the Perched/USG and USG/LSG communication areas are shown in Figures 2 through 4
- The COPCs found in groundwater consist of trichloroethene (TCE) and its daughter products cis- and trans-1,2-dichloroethene (cis/trans-1,2-DCE); 1,1-dichloroethene (1,1-DCE); vinyl chloride (VC); and 1,1,1-trichloroethane (1,1,1-TCA) and its daughter product 1,1-dichloroethane (DCA). These chlorinated aliphatic hydrocarbons are referred to herein as chlorinated volatile organic compounds or CVOCs
- Groundwater flow across the Site in the Perched unit is to the south-southeast at an approximate flow rate of 4.8 ft/day
- Groundwater flow across the Site in the Upper Sand & Gravel unit is to the southwest at an approximate flow rate of 5 ft/day
- Groundwater flow across the Site in the Lower Sand & Gravel unit is to the south-southwest at an approximate flow rate of 2.4 ft/day.

The distribution of COPCs is as follows:

- Residual mass of CVOCs in soil in the Perched aquifer and upper confining layer consist of approximately 2,700 lbs of CVOCs over an approximate 17-acre area from the southeast area of the Site north through the center of Buildings B and C. The residual mass of CVOCs in soil in the USG and lower confining layer consist of approximately 890 lbs of CVOCs located northeast of former Building D. In the LSG, the residual mass of CVOCs is approximately 770 lbs, at the mid-section of the aquifer in the area of OSMW-3D
- TCE and 1,1,1-TCA have the highest observed groundwater concentrations within the Perched aquifer, with the highest concentrations located at the southeastern area of the site near the property line
- Cis-1,2-DCE and vinyl chloride have the highest observed USG groundwater concentrations located at the southeastern area of the Site and off-site to the southeast
- Cis-1,2-DCE and vinyl chloride have the highest observed LSG groundwater concentrations located at the south area of the Site and off-site to the south-southwest.

Additional information on the distribution of CVOCs in the subsurface and a summary of the CSM is presented in the *Hydraulic Control Interim Remedial Measure (IRM) Work Plan* (O'Brien & Gere, 2009).

As part of Site soil and groundwater investigations, microcosm studies were performed to evaluate the biodegradation of COPCs in groundwater. CVOC data and microcosm study results indicate indigenous organisms (*Dehalococcoides ethanogenes* (DE)) capable of degrading TCE exist in site groundwater. Intrinsic biodegradation is occurring in the USG and LSG and together with other natural attenuation mechanisms may be affecting the overall limits of the groundwater CVOC plume.

1.2 OBJECTIVES AND SCOPE OF WORK

Compound specific isotope analysis (CSIA) has been increasingly used as an indicator of chemical and biological degradation of chlorinated solvents in groundwater as well as a tool to distinguish different plumes (*i.e.*, fingerprinting) and trace them back to the release or source area. The objectives for CSIA at the Site are:

- To support further development of the Conceptual Site Model (CSM) under conditions not yet affected by IRM pumping
- To better understand chemical migration pathways between impacted areas
- To further evaluate biodegradation[1] rates.

Stable carbon isotope analysis was conducted in August 2008 on select groundwater samples from the LSG aquifer to identify the potential for biodegradation. Groundwater samples were submitted to Life Science Laboratories, Inc. of Syracuse, New York for VOC analysis. Selected samples were analyzed for carbon isotope ratios ($^{13}C/^{12}C$) at the University of Toronto Stable Isotope Laboratory. Preliminary results indicated enrichment in ^{13}C in CVOC compounds in some downgradient wells, indicating that biodegradation is occurring. Results of preliminary isotope analysis and analysis of biogeochemical indicators of the occurrence of biodegradation and natural attenuation were summarized in *Hydraulic Control Interim Remedial Measure (IRM) Work Plan* (O'Brien & Gere, 2009).

An additional groundwater sampling event was conducted by O'Brien & Gere in November 2009 for analysis of volatile organic compounds (VOCs) as well as ^{13}C and ^{37}Cl stable isotopes. Groundwater samples were

[1] While it is recognized that isotopic fractionation can occur during biodegradation or abiotic transformation, the term biodegradation is used within this report to reflect the numerous laboratory studies that have demonstrated that significant fractionation does occur during biodegradation. In addition, the process used to derive biodegradation rates presented in this report is based on the use of enrichment factors that were derived for biodegradation processes. While the traditional view is that natural abiotic transformation is insignificant compared with biodegradation, this view is changing, and additional research continues to be conducted into biochemical reaction rates and the use of CSIA to distinguish between abiotic and biodegradation processes (Hunkeler et al., 2008).

submitted to TestAmerica Laboratories in Buffalo, New York for VOC analysis. Selected samples were analyzed for carbon isotope ratios ($^{13}C/^{12}C$) at the University of Toronto Stable Isotope Laboratory. Analysis for chlorine isotope ratios ($^{37}Cl/^{35}Cl$) was conducted by the University of Waterloo Environmental Isotope Laboratory. Initial isotope results were received in mid-February 2010, with results of additional confirmation analysis received at the end of March 2010.

This report summarizes the field activities and analyses conducted during the stable isotope study at the Site.

2. METHODS

Groundwater samples for stable isotope analysis were collected in August 2008 and November 2009 during a round of previously scheduled quarterly or IM performance sampling. Groundwater samples were collected using either low-flow or passive bag sampling methods, as described below.

2.1 COLLECTION OF GROUNDWATER LEVELS

Static water levels were recorded at each monitoring well using an electronic water level indicator with a stainless steel probe prior to collecting the groundwater samples. The depth to water level was measured from the top-of-well-casing reference point. Measurements were collected to an accuracy of 0.01 ft. Before each use, the water level indicator was decontaminated with a distilled water/alconox wash and distilled water rinse.

2.2 COLLECTION OF VOC SAMPLES

During the August 2008 sampling event, ground water samples were collected from the monitoring wells in accordance with the protocols described in Appendix C of the May 2003 Supplemental Investigation Work Plan. The low-flow sampling methods involved inserting a stainless steel submersible pump (attached to dedicated polyethylene tubing) to the approximate midpoint of the screened interval of the well and then purging at a rate that produced less than 0.3 ft of drawdown in the well. While the well was being purged, ground water quality parameters consisting of pH, conductivity, temperature, oxidation-reduction potential (ORP), turbidity, and dissolved oxygen (DO) were monitored continuously using an in-line flow-cell and recorded at approximately 5-minute intervals. Once the water quality parameters stabilized, ground water samples were collected directly from the tubing and placed in pre-cleaned (HCl preserved) sample containers supplied by the analytical laboratory. The sample containers were labeled and placed in an ice filled cooler, along with a trip blank and chain-of-custody (COC) form, which was maintained and accompanied the samples, and shipped via overnight courier to Life Science Laboratories, Inc. of Syracuse, New York. The samples were analyzed for volatile organic compounds (VOCs) by USEPA Method 8260B. Samples were also collected from selected wells for various water quality parameters including metals by USEPA Methods 3010A/6010B; alkalinity by method SM18 2320B; chloride, sulfate and nitrate by USEPA Method 300.0; and dissolved gases by RSK-175/USEPA Method 8015B. Following VOC analysis, the group of wells selected for dissolved gas analysis were also selected for possible stable carbon isotope analysis and submitted to the isotope laboratory as discussed below. Purge water and decontamination fluids generated during sampling were contained in 55-gallon DOT-approved steel drums and were properly disposed of by Clean Harbors, Incorporated.

During the November 2009 sampling event, groundwater samples were collected from the monitoring wells in accordance with the protocols described in the USEPA-approved Sampling and Analysis Plan (SAP) dated June 2009. In accordance with the SAP, samples for VOC analysis were collected using the passive bag sampling method. The passive bag sampling method involved inserting a passive diffusion bag by means of a thin stainless steel cable to the approximate midpoint of the screened interval. Three passive diffusion bags were installed across the well screen interval for selected wells to allow sufficient volume for VOC and stable isotope analyses. A minimum of two weeks were then allowed to pass, giving water inside the bag time to equilibrate to the same chemical levels that exist within the aquifer. During sampling, the middle bag was removed and immediately poured into pre-cleaned (HCl preserved) sample containers supplied by the analytical laboratory for VOCs analysis. Contents of the other two passive bags (upper and lower) were collected in 40 ml VOCs vials, preserved with NaOH (pH>10), and submitted to the isotope laboratory as discussed below. Once all the passive bags were removed from the well, groundwater quality parameters consisting of pH, conductivity, temperature, ORP, turbidity, and DO measurements were collected *in-situ* utilizing a submersible water parameter meter. The sample containers were labeled and placed in an ice filled cooler, along with a trip blank and chain-of-custody (COC) form which was maintained and accompanied the samples. The samples for VOC analyses were shipped via overnight courier to Test America, of Buffalo, New York for analysis of VOCs by USEPA Method 8260B.

Quality Assurance/Quality Control (QA/QC) samples were collected with each round of groundwater samples. These samples were collected in accordance with the site SAP at a frequency of one blind duplicate and one matrix spike/matrix spike duplicate (MS/MSD) per twenty samples and one equipment blank, either per day or

per twenty samples, whichever was more frequent. One trip blank was submitted for analysis with each cooler containing groundwater samples for VOC analyses. A Level III data package was requested from the laboratory.

2.3 STABLE ISOTOPE ANALYSIS

During the August 2008 groundwater sampling event, eight 40 ml VOC vials were obtained from each selected well for the purpose of ^{13}C stable isotope analysis. Collected groundwater was preserved with HCl (pH<2). Samples were placed in a cooler (keeping samples at 4 degree C) and shipped via overnight courier for delivery to the University of Toronto, Canada. The samples were refrigerated and stored at the University of Toronto until the VOCs results were received from Life Science Laboratories. The holding time for CSIA samples is 12 weeks, allowing ample time for turnaround on the VOC analysis.

During the November 2009 groundwater sampling event, eight 40 ml VOC vials (four vials from each passive diffusion bag) were obtained from each well for the purpose of ^{13}C and ^{37}Cl stable isotope analysis. Collected groundwater was preserved with NaOH (pH>10). The COC form identified each vial using the following nomenclature: well ID/passive diffusion bag interval/date of retrieval. Samples were placed in a cooler (keeping samples at 4 degree C) and shipped via overnight courier for delivery to Dr. Orfan Shouakar-Stash at the University of Waterloo, Ontario, Canada. The samples were refrigerated and stored at the University of Waterloo until the VOCs results were received from TestAmerica Laboratories. As mentioned above, the holding time for CSIA samples is 12 weeks, allowing ample time for turnaround on the VOC analysis.

Stable carbon isotope analysis was performed at the Stable Isotope Laboratory at the University of Toronto, Canada. Stable chlorine isotope analysis was performed at the University of Waterloo Environmental Isotope Laboratory (EIL), Ontario, Canada. The analytical procedures are summarized in Appendix A. A minimum VOC concentration is necessary to support analysis of isotopic ratios (*i.e.*, keep uncertainty within acceptable limits). Uncertainty incorporates both precision (reproducibility) and accuracy. The criteria for "acceptable limits" are dependent on the methods and instruments used. For example, most laboratories can reach a standard deviation of the mean of triplicate samples of $\pm$0.5 ‰ (Hunkeler *et al.*, 2008). General criteria used by the University of Waterloo and the University of Toronto isotope laboratories are included in Appendix A.

3. RESULTS – AUGUST 2008

3.1 GROUNDWATER SAMPLING OVERVIEW

Groundwater samples for stable carbon isotope analysis were collected during the third quarter ground water sampling event performed the weeks of July 28, August 4, and August 11, 2008. Samples for isotope analysis were collected during August 6-12, 2008 from a total of 9 monitoring wells completed in the LSG aquifer using methods described in Section 2. The following LSG monitoring wells were sampled during the groundwater sampling event (see Figure 1 for well locations):

Perched Aquifer	USG Aquifer	LSG Aquifer
Not Sampled	Not Sampled	AF-21D
		TMW-2D
		OSMW-1D
		OSMW-3D
		OSMW-4D
		OSMW-5D
		OSMW-6D
		OSMW-7D
		OSMW-8D

3.2 FIELD MEASUREMENTS

Field water quality parameters (pH, conductivity, temperature, ORP, DO, and turbidity) collected during the August 2008 sampling event are summarized in Table 1. Field measurements of DO ranged from 0.18 to 0.81 mg/l for the above-listed wells completed in the LSG aquifer. ORP values for these wells ranged from -173 to -225 mv.

Groundwater level measurements and static elevations for the August 2008 sampling event are summarized in Table 2 (O'Brien & Gere, 2008b).

3.3 ANALYTICAL RESULTS

3.3.1 VOCs

Groundwater analytical results are summarized in Table 4. Included are the VOC results for the three chlorinated compounds that were further evaluated by isotope analysis: TCE; cis-1,2-DCE; and VC.

3.3.2 Stable Isotopes

As mentioned in Section 2.3, a minimum VOC concentration is necessary to support analysis of isotopic ratios (*i.e.*, keep uncertainty within acceptable limits). Based on the 9 wells sampled and the quantitation level of VOCs, groundwater samples were analyzed for stable carbon isotopic ratios. Groundwater samples selected from the LSG aquifer and the specific VOC analyzed for carbon isotopic ratios are summarized in Table 3.

The $\delta^{13}C$ values of three chlorinated compounds (TCE, cis-1.2-DCE, and VC) of samples from the LSG aquifer were determined and are summarized in Table 4. The $^{13}C/^{12}C$ ratios are reported in the delta notation ($\delta^{13}C$) referenced to the V-PDB (Vienna-PeeDee Belemnite) standard.

The delta notation is defined as $\delta = (R_{sample}/R_{reference} - 1) \times 1000$, where R_{sample} and $R_{reference}$ are the carbon isotope ratios of the aqueous sample and the respective standards. The results are reported as parts per thousand, or per mil, and shown using the symbol "‰". The total uncertainty (potential error) for the carbon isotope analysis is ±0.5 ‰ for all CVOCs (Appendix A). As discussed in section 2.3, uncertainty incorporates both precision (reproducibility) and accuracy (Hunkeler *et al*., 2008).

3.3.3 QA/QC

The laboratory analytical results for CVOCs were independently validated by O'Brien & Gere to assess data quality. With the exception of dilutions performed during the analyses, sensitivity requirements were met for the sample data. The overall data usability with respect to completeness is 100 percent for the VOC data. The VOC data were also determined to be usable for qualitative and quantitative purposes. The data validation summary report, laboratory analytical data sheets and COC forms are provided in the 2008 Third Quarter Groundwater Sampling report (O'Brien & Gere, 2008b).

Laboratory QA/QC for stable isotopes followed the procedures outlined in Appendix A. QA/QC procedures related to stable isotope analysis such as precision (reproducibility), accuracy, working standards, and maintaining linearity are referenced in Appendix A. No deviations from these procedures were reported.

4. RESULTS – NOVEMBER 2009

4.1 GROUNDWATER SAMPLING OVERVIEW

Groundwater samples for stable isotope analysis were collected in November 2009 during a round of quarterly and performance sampling. The quarterly sampling was being conducted as routine quarterly sampling associated with the GE Aviation RCRA Corrective Action Program in Evendale, Ohio. The performance sampling was conducted as part of baseline groundwater analysis prior to startup of the proposed RCRA Interim Measures groundwater extraction and treatment system. Groundwater samples were collected from 16 wells, plus 8 additional USG wells, for a total of 24 wells (as listed below). Monitoring well sampling included sampling the wells using passive diffusion bags. The 24 wells include monitoring wells from three aquifers (four monitoring wells in the Perched aquifer, seventeen monitoring wells in the middle USG aquifer, and three monitoring wells in the deep LSG aquifer. In addition to the diffusion bag for performance sampling, two additional diffusion bags (*i.e.* total of 72 passive diffusion bags) were placed in each well for stable isotopes analysis. The bags were placed in each well stacked above each other, within the well screen. The middle bag was utilized for VOCs analysis. Bags were placed during the third and fourth weeks of October (October 20-21, 2009; October 29, 2009) and were recovered during November 4-11, 2009 for VOC analysis. Following the collection of in-situ field parameters, the top and bottom bags were immediately re-inserted into the well and removed on November 12, 2009 for stable isotope analysis.

The following Perched, USG, and LSG monitoring wells were sampled during the groundwater sampling event (see Figure 1 for well locations):

Perched Aquifer	USG Aquifer		LSG Aquifer
OSMW-10P	OSMW-1S	AF-2S	OSMW-3D
PMW-3P	OSMW-4S	AF-3S	OSMW-1D
AF-7P	OSMW-10S	AF-4S	PMW-3D
AF-24P	OSMW-11S	GM-1	
	OSMW-12S	GM-3S	
	OSMW-13S	GM-7S	
	PMW-3S	GM-10S	
	AF-7S	GM-11S	
	H-222		

Seven of the monitoring wells (AF-7P, AF-24P, AF-7S, OSMW-1S, OSMW-4S, OSMW-1D, and OSMW-3D) were sampled during the Fourth Quarter 2009 sampling event. The remaining monitoring wells were sampled during the November 2009 performance monitoring event.

4.2 FIELD MEASUREMENTS

Based on review of calibration logs for field equipment, the field parameters collected during the November 2009 sampling event are considered invalid due to a malfunctioning meter.

Groundwater level measurements and static elevations collected during an October 2009 area-wide monitoring event are summarized in Table 2. Groundwater elevation data from the October 2009 event are presented in

Figures 2 through 4 for the Perched, USG, and LSG aquifers, respectively. These groundwater levels were used to calculate the hydraulic gradient between specific monitoring wells as summarized in Table 6. The interwell gradients were approximately 0.003 ft/ft in the Perched aquifer, ranged from 0.001 to 0.004 ft/ft in the USG aquifer, and were approximately 0.0008 ft/ft in the LSG aquifer.

4.3 ANALYTICAL RESULTS

4.3.1 VOCs

Groundwater analytical results are summarized in Table 5. Included are the VOC results for the five chlorinated compounds that were further evaluated by isotope analysis: TCE; cis-1,2-DCE; VC; 1,1,1-TCA; and 1,1-DCA.

4.3.2 Stable Isotopes

As mentioned in Section 2.3, a minimum VOC concentration is necessary to support analysis of isotopic ratios (*i.e.*, keep uncertainty within acceptable limits). Based on the 24 wells sampled and the quantitation level of VOCs, groundwater samples were analyzed for either stable carbon or stable chlorine isotopic ratios or both isotopic ratios. Groundwater samples selected from each aquifer and the specific VOC analyzed for either or both isotopic ratios are summarized in Table 3.

The $\delta^{13}C$ and $\delta^{37}Cl$ values of five chlorinated compounds (TCE, cis-1.2-DCE, VC, 1,1,1-TCA, and 1,1-DCA) of samples from the three different aquifers (Perched, USG and LSG aquifers) were determined and are summarized in Table 3. The $^{13}C/^{12}C$ ratios are reported in the delta notation ($\delta^{13}C$) referenced to the V-PDB (Vienna-PeeDee Belemnite) standard. The $^{37}Cl/^{35}Cl$ ratios are reported in the delta notation ($\delta^{37}Cl$) referenced to the SMOC (Standard Mean Ocean Chloride) standard (except for the 1,1-DCA results that were reported relative to 11DCA-A, an in-house standard of EIL).

The delta notation (δ) for carbon or chlorine isotopic ratios is as defined in Section 3.3.2. As referenced, the total uncertainty (potential error) for the carbon isotope analysis is ±0.5 ‰ for all CVOCs (Appendix A). The uncertainty for chlorine isotope analysis is usually ± 0.1 ‰ for TCE and cis-1,2-DCE, ± 0.16 ‰ for VC and usually less than ± 0.20 ‰ for 1,1-DCA and 1,1,1-TCA (Appendix A).

4.3.3 QA/QC

The laboratory analytical results for CVOCs were independently validated by O'Brien & Gere to assess data quality. With the exception of dilutions performed during the analyses, sensitivity requirements were met for the sample data. The overall data usability with respect to completeness is 100 percent for the VOC data. The VOC data were also determined to be usable for qualitative and quantitative purposes. The data validation summary report for the Fourth Quarter 2009 sampling event is included in the Groundwater Sampling Report Fourth Quarter 2009 (O'Brien & Gere, 2010). The data validation summary report for the November 2009 performance monitoring event is provided in Appendix B of this report.

Laboratory QA/QC for stable isotopes followed the procedures outlined in Appendix A. QA/QC procedures related to stable isotope analysis such as precision (reproducibility), accuracy, working standards, and maintaining linearity are referenced in Appendix A. No deviations from these procedures were reported.

5. DISCUSSION

Understanding of groundwater and solute flowpaths, chemical distribution, and biodegradation rates is essential to evaluation of isotopic data from a site. These aspects of the conceptual site model are summarized below and are followed by a discussion of the isotope sampling results.

5.1 HYDROGEOLOGIC CONDITIONS AND GROUNDWATER FLOW

Perched Aquifer

The Perched aquifer is the uppermost water-bearing unit, comprised of interbedded sand and gravel deposits with varying amounts of silt and clay. The soils are generally characterized by poorly graded, coarse to fine grained sand (SP). The average saturated thickness of the Perched aquifer is approximately 20 feet, with the bottom of the Perched aquifer ranging in depth from 24 to 42 feet below grade (fbg).

Groundwater in the Perched aquifer consistently flows to the south and southeast across the Site, with a historical hydraulic gradient of 0.002 ft/ft to 0.02 ft/ft, and an average groundwater velocity of 5 ft/day. The potentiometric surface for the Perched aquifer in October 2009 is shown in Figure 2. Estimates of biodegradation rates using stable isotope data requires an estimate of travel time along a particular groundwater flow path. The average groundwater velocity across a site is estimated in a direction perpendicular to the equipotentiometric line (assuming an isotropic aquifer). The hydraulic gradient between two wells (interwell hydraulic gradient) is used to estimate a flow component of the average groundwater velocity and data between a series of monitoring wells is used to incorporate the behavior of the particular CVOC in each flow path to account for the heterogeneous nature of the plume. Based on the October 2009 water level data, interwell hydraulic gradients and groundwater velocities were calculated and are summarized in Table 6. The interwell hydraulic gradient between AF-7P and wells PMW-3P and OSMW-10P was approximately 0.003 ft/ft. The groundwater velocity between well AF-7P and wells PMW-3P and OSMW-10P is estimated at approximately 4 ft/day.

Upper Confining Layer

The Upper Confining Layer is comprised of gray clayey silt (ML), with little to some coarse to fine grained sand, and trace to little coarse to fine gravel. The top of the Upper Confining Layer ranges from 29 fbg to 39 fbg and the bottom of the Upper Confining Layer ranges in depth from 37 fbg to 59 fbg. The thickness of the Upper Confining Layer ranges from absent (zero) to 28 ft, with the thickest area along the western side of AFP 36 (Figure 2). The Upper Confining Layer was not present in borings (PMW-3P, OSMW-10P, H-221) at the southeastern side of AFP 36, confirming the communication area between the Perched and USG aquifers in this area. The estimated extent of the Perched/USG communication area is shown in Figure 2, based on drilling data and an isopach thickness of less than 2 feet.

USG Aquifer

The USG aquifer is comprised of two areas of thick sand deposits - one on the western side of AFP 36, extending off-site to the west and south and the other sand deposit on the east side of AFP 36, extending to the east and south. Between these sand deposits, the USG aquifer is present but of limited thickness. The soils are poorly graded, predominantly medium to fine grained sand (SP to SP-SM).

The USG aquifer merges with the Perched aquifer on the southeast side of AFP 36 (*i.e.*, Perched/USG communication area) and off-site to the southeast and south of AFP 36, and also communicates with the LSG aquifer on the western side of AFP 36 (*i.e.*, USG/LSG communication area). The USG thickness ranges from 4 to 21 feet at the Site; however, thicknesses of up to approximately 30 ft have been documented during previous on-site investigations and greater than 40 ft thick off-site to the south. The bottom of the USG aquifer ranges in depth from 54 fbg to 63 fbg.

Groundwater in the USG aquifer on the western side of AFP 36 flows predominately to the southwest. On the eastern side of AFP 36, groundwater flow in the USG aquifer is to the south and southeast. The historical hydraulic gradient is approximately 0.002 ft/ft to 0.007 ft/ft across the Site, with an average groundwater velocity of 5 ft/day. The potentiometric surface for the USG aquifer in October 2009 is shown in Figure 3.

Interwell hydraulic gradients and groundwater velocities are summarized in Table 6. The interwell hydraulic gradient ranged from 0.001ft/ft to 0.004 ft/ft. The groundwater velocity between wells AF-2S, AF-4S, and AF-7S and select downgradient wells ranged from approximately 4 ft/day to 10 ft/day. The groundwater velocity between OSMW-10S and H-222 was approximately 13 ft/day.

Lower Confining Layer

The Lower Confining Layer is comprised of a gray clayey silt or silt (ML), including trace to little medium to fine grained sand and trace fine gravel. The top of the Lower Confining Layer ranges from 54 fbg to 63 fbg and the bottom of the Lower Confining Layer ranges in depth from 62 fbg to 103 fbg in the AFP 36 area based on historical soil boring data. The thickness of the Lower Confining Layer ranges from absent (zero) to 35 ft, with the thickest area along the eastern side of AFP 36. The Lower Confining Layer was thin to non-existent in borings (*i.e.*, AF-20D) located on the west-southwestern side of AFP 36, confirming the communication area between the USG and LSG aquifers in this area. The estimated extent of the USG/LSG communication area is shown in Figure 4, based on drilling data and an isopach thickness of less than 2 feet.

LSG Aquifer

The LSG aquifer consists of a gray poorly graded fine to coarse grained sand and gravel (SP-SM) that becomes coarser with depth, and contains trace to little fines. The top of the LSG aquifer is encountered at approximately 65 to 100 fbg, with an average saturated thickness of approximately 80 to 100 feet. The USG aquifer communicates with the LSG aquifer on the western side of AFP 36 (*i.e.*, USG/LSG communication area).

Based on historical data and recent monitoring events, groundwater in the LSG aquifer consistently flows across the Site to the south-southwest, with an hydraulic gradient of 0.002 ft/ft and an average groundwater velocity of 2 ft/day. Groundwater recovery operations at the Pristine Superfund site, located southeast of the GE site, have created an area of depressed groundwater and a southeasterly flow component. The potentiometric surface for the LSG aquifer in October 2009 is shown in Figure 4. Interwell hydraulic gradients and groundwater velocities are summarized in Table 6. The interwell hydraulic gradient between OSMW-3D and TMW-2D was estimated at 0.0008 ft/ft, with an intewell groundwater velocity of approximately 0.4 ft/day.

5.2 CVOC DISTRIBUTION

Groundwater analytical results for November 2009 are summarized in Table 5. Included are the VOC results for five chlorinated compounds, including the primary products TCE and 1,1,1-TCA and their degradation or daughter products cis-1,2-DCE and VC for TCE and 1,1-DCA for 1,1,1-TCA. The lateral distribution of TCE and 1,1,1-TCA within the Perched and USG aquifers during November 2009 is presented in Figures 5 through 8. The lateral distribution of TCE within the LSG is shown in Figure 9. The November 2009 CVOC data confirmed the general plume distribution characterized in the CSM (O'Brien & Gere, 2009). This includes the presence of elevated concentrations of TCE and TCA in the Perched aquifer and elevated daughter product concentrations of cis-1,2-DCE and VC in the USG, with some degree of mixing occurring in the Perched/USG communication area. In addition, although CVOC data was limited for the LSG aquifer, the concentrations of parent and daughter products in the LSG were measured at concentrations of less than 200 ug/l (with the exception of cis-DCE).

Within the Perched aquifer, TCE and 1,1,1-TCA concentrations were the highest CVOCs, ranging from 270 to 800 µg/l (TCE) and from 230 to 930 µg/l (TCA). Cis-1,2-DCE and 1,1-DCA concentrations were within the similar range of approximately 13 to 59 µg/l. VC was detected in AF-24P and OSMW-10P at concentrations of 1 and 5µg/l, respectively.

Within the USG aquifer, cis-1,2-DCE and VC concentrations were the highest CVOCs. Cis-1,2-DCE concentrations ranged from 15 µg/l (OSMW-10S) to 3000 µg/l (OSMW-1S). VC concentrations ranged from 9 µg/l (OSMW-10S) to 660 µg/l (AF-7S). Cis-1,2-DCE and VC were not detected in well GM-10S. TCE and 1,1,1-TCA were detected in select wells at concentrations ranging from 7.9 µg/l to 95 µg/l and from 6 µg/l to 310 µg/l, respectively. Concentrations of 1,1-DCA ranged from 9 µg/l (GM-10S) to 100 µg/l (PMW-3S). 1,1-DCA was not detected in OSMW-4S.

Within the LSG aquifer, TCE was detected in OSMW-3D and PMW-3D at concentrations of 97 µg/l and 130 µg/l, respectively. TCA was detected in PMW-3D at a concentration of 210 µg/l. Concentrations of cis-DCE and VC were detected in all wells, ranging from 46 µg/l to 820 µg/l and from 17 µg/l to 210 µg/l, respectively. 1,1-DCA was detected in all wells at concentrations of 6 to 97 µg/l.

5.3 GEOCHEMICAL INDICATORS OF BIODEGRADATION

As discussed in Section 1.2, VOC data and microcosm study results indicate the presence of indigenous organisms (*Dehalococcoides ethanogenes*, or DE) capable of degrading TCE. The data also suggested that dechlorination of VC to ethene may be inhibited in the presence of TCA. The predominant terminal electron acceptor process (TEAP) of the Perched aquifer is borderline oxic to denitrifying based on the presence of terminal electron acceptors (such as nitrate and sulfate) and field parameter data. These conditions are not optimal for reductive dechlorination. Groundwater redox conditions of the USG and LSG are more reducing than the Perched aquifer and are more favorable for biodegradation via reductive dechlorination. The USG and LSG redox conditions are characterized by both sulfate reducing and methanogenesis based on the preponderance of evidence ranging from TEA and field parameter data to VOC and methane concentrations in the groundwater. During the August 2008 sampling event, geochemical indicators of the occurrence of biodegradation and natural attenuation were also collected (O'Brien & Gere, 2009). The data summarizing the results of these studies are summarized in Appendix C.

DO values tend to be less than approximately 0.5 mg/l in the majority of recent groundwater samples collected at the Site, with the Perched aquifer samples having the highest measurements (Table1). As indicated in Appendix C, DO ranged from 0.11 mg/l (TMW-2P) to 1.46 mg/l (TMW-1P) in the Perched aquifer. In the USG, DO ranged from 0.1 mg/l (OSMW-1S) to 0.2 mg/l (AF-5S). DO concentrations were similar in the LSG, ranging from 0.1 mg/l (OSMW-1D) to 0.3 mg/l (OSMW-3D).

ORP data ranged from +49.4 mv (AF-5P) in the Perched aquifer to -567 mv (TMW-2D) in the LSG (Appendix C). These measurements compare with ORP values collected during the August 2008, August 2009 and December 2009 sampling events (Table 1). During these events, field measurements showed ORP ranged from -147 mv to +102 mv in the Perched aquifer; -56 mv to -220 mv in the USG aquifer; and -140 mv to -225 mv in the LSG aquifer; corresponding with the above-listed conclusions regarding biogeochemical conditions and the predominant TEAP.

Intrinsic biodegradation is occurring in all three aquifers, particularly the USG and LSG, and together with other natural attenuation mechanisms is affecting the overall limits of the groundwater CVOC plume. These conclusions are supported independently by the analysis of stable carbon and chlorine isotope data, as presented in the following section.

5.4 ISOTOPE DATA EVALUATION

The $\delta^{13}C$ and $\delta^{37}Cl$ values of five chlorinated compounds (TCE, cis-1,2-DCE, VC, 1,1,1-TCA, and 1,1-DCA) of samples from the three different aquifers (Perched, USG and LSG aquifers) are summarized in Table 5. The distribution of $\delta^{13}C$ and $\delta^{37}Cl$ values for individual wells for TCE and 1,1,1-TCA within the Perched and USG aquifers during November 2009 is presented in Figures 5 through 8. The $\delta^{13}C$ and $\delta^{37}Cl$ values for TCE for wells in the LSG are shown in Figure 9.

Conventional approaches used to estimate the rate of biodegradation involve comparing changes in contaminant concentrations with travel time along a flow path within an aquifer. Application of CSIA provides an independent and typically more conservative approach, to estimate the extent and rate of biodegradation along a flow path. The steps involved in quantifying biodegradation using CSIA include the following (Hunkeler et al., 2008):

- Evaluate the stable isotope data for fit with the Rayleigh model
- Determine the primary or source isotopic signature
- Select an appropriate isotopic enrichment factor
- Calculate the extent of biodegradation and convert to a biodegradation rate

Each of these steps is presented in the following sections. Analysis of the stable isotope data involved the following two general components: (1) a basic evaluation of overall trends and correlation of isotope fractionation and CVOC concentration (Section 5.5.1), followed by (2) a more detailed evaluation of biodegradation rates along groundwater flowpaths (Section 5.5.4). While general trends and production of daughter products are presented and discussed, this preliminary data analysis focused on the biodegradation rates of the parent products TCE and 1,1,1-TCA, to avoid the additional uncertainty associated with the simultaneous production and degradation of daughter products.

5.5.1 Evaluate the Isotope Data for Fit with Rayleigh Model

The Rayleigh equation (Hunkeler *et al*., 2008) can be used to predict the extent of chemical degradation, particularly biodegradation, from changes in the value of the stable isotopic ratio ($\delta^{13}C$ or $\delta^{37}Cl$). Data fit with the Rayleigh model was examined to confirm whether biodegradation is indicated by a correlation between attenuation and isotopic enrichment. A basic evaluation of chemical degradation was performed by trend analysis of CVOC concentrations and isotopic enrichment in each aquifer. More detailed evaluation of chemical degradation, by evaluation of concentrations and isotopic enrichment along specific solute flowpaths, may be performed in later phases of work if warranted by project objectives.

Graphs of $\delta^{13}C$ and $\delta^{37}Cl$ versus the natural log of concentration of each CVOC (TCE, cis-1,2-DCE, VC, 1,1,1-TCA, and 1,1-DCA) are presented in Figures 10 through 19. Values of $\delta^{13}C$ and $\delta^{37}Cl$ from all samples for each CVOC as well as within each aquifer were plotted. The placement of all samples on a semi-log plot shows a general increased enrichment of ^{13}C and ^{37}Cl (*i.e.*, less negative value of $\delta^{13}C$ and $\delta^{37}Cl$) with a natural logarithmic decrease in concentration; indicative of a Rayleigh correlation. The existence of the Rayleigh correlation would indicate that biodegradation or abiotic transformation is the significant process influencing the change in CVOC concentration. With regards to TCE this is apparent for both isotopes in all three aquifers. With 1,1,1-TCA, this is apparent for ^{13}C for the Perched and USG, and for the Perched with ^{37}Cl.

To facilitate data evaluation, isotope data were plotted by hydrogeologic unit. Where a negative slope indicative of a Rayleigh correlation was indicated by the data (at least three data points), a regression trend line and R-squared value based on all the data points for each aquifer was also included on each aquifer plot. As outlined in Hunkeler et al., (2008), those data points showing greater enrichment (less negative) than the Rayleigh correlation line indicate mixing with another source, while data points showing less enrichment (more negative) indicate the influence of transport parameters such as dilution, dispersion, sorption, and volatilization. Variations in well screen length and location relative to the contaminant plume can also cause the data points to fall off the Rayleigh correlation line. Due to these and other possible factors, the data exhibited a wide range of R-squared values (0.1 to 0.9). For three of the plots, the regression trend line showed a positive slope for the data points. These include $\delta^{37}Cl$ for 1,1,1-TCA in the USG aquifer (Figure 17), $\delta^{13}C$ data for 1,1-DCA in the Perched aquifer (Figure 18), and $\delta^{37}Cl$ for 1,1-DCA in the Perched aquifer (Figure 19).

As discussed in Section 2.1, the total analytical uncertainty for $\delta^{13}C$ analysis is $\pm$0.5‰ and even less for $\delta^{37}Cl$ analysis. Therefore, observed fractionation should be at least > 1‰, and on the order of 2‰ for reliable interpretation. When interpreted along a groundwater flow path, a qualitative indication of biodegradation or abiotic transformation is observed when values of $\delta^{13}C$ or $\delta^{37}Cl$ in downgradient wells are enriched (less negative) by 2‰ or greater as compared to values in the upgradient well.

Graphs of TCE and 1,1,1-TCA for the Perched and USG aquifers show a trend indicative of the Rayleigh correlation for ^{13}C and ^{37}Cl data (see Figures 10, 11, 16, and 17). Data plots are limited for the LSG data due to a total of three or less well sample points. A trend indicative of the Rayleigh correlation is particularly apparent if those wells known to exist within the Perched/USG communication are identified or taken into account. For

example, this would include wells PMW-3P/3S, OSMW-10P/10S, and H-222 (see Figures 10, 11, 16, and 17 for the Perched and USG aquifers). A trend indicative of the Rayleigh correlation is also shown for cis-DCE in the Perched and USG aquifers (Figures 12 and 13) and for VC and possibly 1,1-DCA for the USG aquifer (Figures 14, 15, 18, and 19).

Plots for the LSG aquifer sampling in 2008 for cis-1,2-DCE and VC, and $\delta^{13}C$ are included in Figure 20 to further support the limited LSG sampling in 2009. A trend indicative of the Rayleigh correlation is shown for these two CVOCs based on the 2008 data. These preliminary results showed enrichment in ^{13}C in CVOC compounds in some downgradient wells, indicating that biodegradation is occurring. For example, $\delta^{13}C$ values for cis-1,2-DCE showed enrichment (less negative values) between OSMW-3D and downgradient well OSMW-6D, decreasing from -27.4‰ to -5.1‰ (Table 4). For VC, the $\delta^{13}C$ value decreased between OSMW-6D and downgradient well OSMW-8D, from -31.4‰ to -15.4‰.

It is best to plot data taking into account those factors that affect contaminant transport and degradation over time and space. These would include hydrogeologic factors such as groundwater flow direction, influence of aquifer mixing, geochemical conditions, etc. Additional trend and statistical analysis could be performed by removing data associated with wells showing isotope signatures indicative of aquifer mixing or the influence of other conditions. This was not performed during this preliminary analysis but could be done at a future date if warranted.

5.5.2 Determine the Primary Isotopic Signature ($\delta^{13}C_{source}$ or $\delta^{37}Cl_{source}$)

Evaluation of the primary isotopic signature may assist with the identification or confirmation of potential source areas. The primary isotope signature is the isotopic ratio of the CVOC prior to fractionation by biodegradation or abiotic transformations. This is initially estimated from published values for undegraded pure product of TCE and 1,1,1-TCA. The minimum-maximum range and mean carbon and chlorine isotope ratios from different manufacturers and production batches are summarized as follows (Hunkeler *et al.,* (2008)):

TCE

$\delta^{13}C$ – mean: -29‰; with a range of -34 to -23‰

$\delta^{37}Cl$ – mean: 0.9‰; with a range of -3.2 to 3.9‰

1,1,1-TCA

$\delta^{13}C$ – mean: -27‰; with a range of -32 to -26‰

$\delta^{37}Cl$ – mean: -1.5‰; with a range of -3.9 to 1.3‰

In general, when the value of $\delta^{13}C$ or $\delta^{37}Cl$ as measured from field groundwater samples is less negative (more enriched in ^{13}C or ^{37}Cl) than the range of pure substance, degradation is evident at the site. A review of the table (Table 5) and plot (Figure 10) of well data for $\delta^{13}C$ and TCE indicate several wells with $\delta^{13}C$ values less negative than the above-listed range for undegraded product. These wells include: PMW-3P/S/D, AF-2S, AF-4S, H-222, OSMW-10S, OSMW-11S, and OSMW-3D. Well data for 1,1,1-TCA and $\delta^{13}C$ (Figure 16) indicate several wells with $\delta^{13}C$ values less negative than the above-listed range for undegraded 1,1,1-TCA product. These wells include: AF-4S, GM-10S, H-222, and PMW-3S/D.

Conversely, the most negative values of $\delta^{13}C$ or $\delta^{37}Cl$ (i.e., least enriched or most depleted in ^{13}C or ^{37}Cl) may represent a release/source location, particularly in an upgradient location. Based on the data collected, TCE and 1,1,1-TCA concentrations were the most depleted in ^{13}C for well AF-7P (see Figures 10 and 16, respectively). Well AF-7P showed a $\delta^{13}C$ value within the range of undegraded TCE product and more depleted than even the average value for undegraded 1,1,1-TCA product (Table 5).

A review of the table (Table 3) and graph (Figure 11) of well data for TCE and $\delta^{37}Cl$ indicates that due to the wide range of $\delta^{37}Cl$ values for undegraded product, only well OSMW-3D showed $\delta^{37}Cl$ values less negative than

the range from literature. Inversely, well data for 1,1,1-TCA and $\delta^{37}Cl$ (Figure 17) showed all wells with $\delta^{37}Cl$ values less negative than the above-listed range for undegraded 1,1,1-TCA product. Therefore, although enrichment and degradation is evident, the $\delta^{37}Cl$ data from this data set cannot be applied to evaluation of potential sources using this approach.

An alternative approach to estimate the original values of $\delta^{13}C_{source}$ or $\delta^{37}Cl_{source}$ would be to consider the most negative value measured for the CVOC in groundwater at the site. These wells would be indicative of the least degraded material at the site (based on the selected wells sampled). This approach assumes that all spills at a site are from a feedstock/product of consistent isotopic composition, and therefore, may only identify a subset of source areas at sites with multiple releases from different feedstock. Use of a dual isotope (or two-dimensional isotope) approach using both $\delta^{13}C$ and $\delta^{37}Cl$ data may help distinguish multiple sources/releases, however, this was not performed during this preliminary analysis. The most negative value of $\delta^{13}C$ was -25‰ for TCE and -28.1‰ for 1,1,1-TCA, both occurring at AF-7P. These values fall within the range of published values for undegraded product listed above. The lowest value of $\delta^{37}Cl$ was 1.18‰ for TCE and 1.82‰ for 1,1,1-TCA, occurring in wells AF-2S and AF-7P, respectively. These values also fall within or near ($\pm$0.5‰) the above-listed range of published values for undegraded product.

5.5.3 Select an Isotopic Enrichment Factor (ε)

The enrichment factor (ε) is selected for use with the Rayleigh equation to estimate the amount of chemical degradation from upgradient sources or between two monitoring points along a flow path. The enrichment factor can also be used to identify sample data (and associated well locations) that may reflect the influence of different degradation pathways (reaction mechanisms) or assist in inferring other attenuation processes.

For purposes of this evaluation, published isotope enrichment factors derived from laboratory microcosm studies were used , with the assumption that these laboratory-derived values are applicable to the field. The results from traditional laboratory microcosm studies are commonly used to predict the removal of organic constituents in field-scale plumes (Hunkeler et al., 2008). The value of the enrichment factor (ε) is sensitive to the biodegradation pathway; and therefore knowledge of the geochemical conditions (in particular oxidiation-reduction or redox conditions) and microbial populations is important to estimating the most probable pathway for metabolism (or abiotic transformation). The general approach is to use the information from field geochemistry and then select enrichment factors from published literature for the specific CVOC under the relevant redox conditions.

As discussed in Section 4.3, field values of ORP collected during the August 2008, August 2009 and December 2009 sampling events ranged from -147 mv to +102 mv in the Perched aquifer;-56 mv to -220 mv in the USG aquifer; and -140 mv to -225 mv in the LSG aquifer. ORP data measured during previous investigations (Appendix C) ranged from +49.4 mv (AF-5P) in the Perched aquifer to -567 mv (TMW-2D) in the LSG. In addition, DO values tend to be less than approximately 0.5 mg/l in the majority of groundwater samples, with the Perched aquifer samples generally having the highest measurements. It was concluded that the Perched aquifer is borderline oxic to denitrifying based on the TEA and field parameter data. These conditions are not optimal for reductive dechlorination; however, they indicate anaerobic conditions. Additionally, while bulk water conditions are not optimal for reductive dechlorination there may be localized areas/microenvironments which support reductive dechlorination. Groundwater redox conditions of the USG and LSG are more reducing than the Perched aquifer and are favorable for biodegradation via reductive dechlorination. The USG and LSG redox conditions are characterized by both sulfate reducing and methanogenesis based on the preponderance of evidence ranging from TEA and field parameter data to VOC and methane concentrations in the groundwater.

For geochemical conditions characterized as anoxic, anoxic dehalogenating, and methanogenic dehalogenating, the following enrichment factors (ε) have been derived from laboratory microcosm studies and published in the literature for various bacteria and geochemical conditions (Hunkeler et al. (2008); Isodetect GmbH (2007)):

TCE

^{13}C /^{12}C fractionation	Range of ε_C values = -22.9 to -2.5‰ (average = -12.0‰)
^{37}Cl /^{35}Cl fractionation	Range of ε_{Cl} values = -30 to -5.5‰ (average = -11.7‰)

While numerous values are published for TCE under various geochemical and microbial conditions, values for 1,1,1-TCA are not readily available, and only one source of published values for abiotic degradation was obtained.

As described in more detail in Appendix D, the Rayleigh equation can be rearranged to estimate the fraction remaining after biodegradation (*f*):

$$f = e^{(\delta 13C_{gw} - \delta 13C_{source})/\varepsilon)}$$

where $\delta^{13}C_{gw}$ is the measure of the isotope ratio in the organic constituent in the groundwater sample, $\delta^{13}C_{source}$ is the isotopic ratio in the un-fractionated organic constituent before biodegradation has occurred, and epsilon (ε) is the stable isotope enrichment factor.

Using the most negative value of ε predicts the largest value for the fraction remaining after biodegradation (*f*) via the Rayleigh equation, yielding the most conservative estimate of the extent of biodegradation (1-*f*). Conversely, use of the least negative value would yield a higher estimate of the extent of biodegradation. The approach taken as part of this analysis was to use the maximum and minimum values of ε within the range of geochemical conditions for the Site to provide an estimate of the upper and lower boundary of the extent of biodegradation, with the average value used as a best estimate of the extent of biodegradation. While it may be tempting to use field-derived fractionation data to determine isotope enrichment factors, it is not recommended as a general procedure due to complex site hydrogeologic and microbial processes which would yield crude estimates as compared with values from laboratory-derived experiments (Hunkeler et al., 2008).

5.5.4 Calculate the Biodegradation Rate

CSIA provides an independent evaluation of biodegradation rates for comparison with rates derived from conventional methods based on concentration changes between monitoring wells located along a groundwater flow path. Using assumptions of the flow path and groundwater flow rates, the Rayleigh equation can be used to estimate the fraction remaining after biodegradation (*f*), the extent of biodegradation or abiotic transformation (1-*f*), and ultimately, the rate of biodegradation (λ). Details of this approach are included in Appendix D. CSIA may also identify well pairs that do not fit the Rayleigh model, and therefore, should not be used for estimation of biodegradation rates.

The rate of biodegradation (λ) along the groundwater flow path was estimated from the CVOC concentration in the groundwater sample, the extent of biodegradation (1-*f*) from CSIA analyses, and the estimated travel time along the groundwater flow path. Data between a series of monitoring wells was used to incorporate the behavior of the particular CVOC in each flow path to account for the heterogeneous nature of the plume, using methods outlined in Hunkeler (2008).

Biodegradation rates were estimated for both the Perched and USG aquifers based upon the TCE data and are summarized in Table 7. TCE data for the LSG aquifer, from either 2008 or 2009, were insufficient to estimate biodegradation rates. Also, as mentioned in Section 4.4.3, 1,1,1-TCA enrichment factors were not available to provide for additional comparative analysis. The interwell groundwater flow velocity, TCE concentrations, and ^{13}C and ^{37}Cl isotope data were used to estimate a range of values for the rate of biodegradation in each unit. The interwell groundwater velocity was calculated by multiplying the interwell hydraulic gradient by the hydraulic conductivity (Perched (400 ft/day); USG (850 ft/day)), then dividing by the estimated effective porosity (0.25) (see Table 6).

In general, the rate of biodegradation was estimated between the most impacted well and wells located further downgradient as follows:

Perched

AF-7P to PMW-3P

AF-7P to OSWM-10P

USG

AF-2S to AF-4S

AF-2S to PMW-3S

AF-2S to H-222

AF-4S to H-222

OSMW-10S to H-222

The upgradient to downgradient relationship of these wells appears to fit the Rayleigh model (see Figure 10), with the upgradient wells (in particular, AF-7P, AF-2S, and AF-4S) having $\delta^{13}C$ values within the range for undegraded TCE product (i.e., -34 to -23‰).

Values of $\delta^{13}C$ and $\delta^{37}Cl$ at the most impacted well (*i.e.*, the most negative isotope value) were used as estimates of the primary isotope signature (source) or $\delta^{13}C_{source}$ or $\delta^{37}Cl_{source}$. Average values of carbon and chlorine isotope ratios from different TCE manufacturers and production batches were also used for comparison. In addition, the minimum, maximum, and average enrichment factors for TCE were used to generate a range of minimum, maximum, and average values for the rate of biodegradation. In the Perched and USG aquifers, first-order biodegradation rates ranged from 0.00002 to 0.1083 per day, with an average rate of approximately 0.0001 to 0.0226 per day. Biodegradation rates for TCE are reported in the literature to range from 0.0001 to 0.04 per day (U.S. EPA, 1999; Wiedemeier *et al*. 1999).

6. CONCLUSIONS

Based upon the preliminary results of the stable isotope analysis for the GE/AFP36 site and surrounding area, the following conclusions are provided:

- A basic evaluation of the CSIA data was performed, using conservative assumptions, to support further development of the Conceptual Site Model and to better understand biodegradation and chemical migration pathways between impacted areas.
- Intrinsic biodegradation is occurring in the three aquifers (Perched, USG, and LSG), and together with other natural attenuation mechanisms, is affecting the overall limits of the groundwater CVOC plume. CSIA independently supports that biodegradation is the dominant chemical degradation mechanism, based on the data fit with the Rayleigh model.
- Comparison of groundwater sample data for $\delta^{13}C$ and $\delta^{37}Cl$ with a range of published values for undegraded TCE product suggests that TCE releases to the Perched and USG aquifers may have occurred in the area of wells AF-7P and AF-2S, respectively. This evaluation does not preclude the existence of other releases.
- Comparison of groundwater sample data for $\delta^{13}C$ and $\delta^{37}Cl$ with a range of published values for undegraded 1,1,1-TCA product suggests that 1,1,1-TCA releases to the Perched aquifer may have occurred in the area of well AF-7P. Concentrations of 1,1,1-TCA were too low for stable isotope analysis of groundwater from well AF-2S (USG aquifer). This evaluation does not preclude the existence of other releases.
- CSIA was useful for the estimation of biodegradation rates for TCE in the Perched and USG aquifers. TCE data were insufficient to support estimation of biodegradation rates for the LSG aquifer. Also, published enrichment factors for 1,1,1-TCA were not available at the time of this evaluation; therefore, 1,1,1-TCA biodegradation rates could not be estimated. In the Perched and USG aquifers, first-order biodegradation rates for TCE ranged from 0.00002 to 0.1083 per day, with an average rate of approximately 0.0001 to 0.0226 per day; which is consistent with the range of values from published literature.
- Further CSIA is not warranted to meet current project objectives.

7. REFERENCES

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TABLES

Table 1. Summary of Field Groundwater Quality Parameters

Well	April-06						August-08						August-09						December-09					
	pH (S.U.)	Conductivity (µS/cm)	Turbidity (NTU)	Temperature (°C)	DO (mg/L)	ORP (mV)	pH (S.U.)	Conductivity (µS/cm)	Turbidity (NTU)	Temperature (°C)	DO (mg/L)	ORP (mV)	pH (S.U.)	Conductivity (µS/cm)	Turbidity (NTU)	Temperature (°C)	DO (mg/L)	ORP (mV)	pH (S.U.)	Conductivity (µS/cm)	Turbidity (NTU)	Temperature (°C)	DO (mg/L)	ORP (mV)
Perched																								
AF-5P	7.26	853	25	17.8	0.41	17	7.03	1500	5	17.3	0.03	-12	7.43	962	--	16.2	**	102	--	--	--	--	--	--
AF-7P	7.25	1305	34	18.5	0.28	-2	7.15	1110	21	18.1	0.05	-79	7.75	706	--	18.6	**	5	--	--	--	--	--	--
AF-24P	--	--	--	--	--	--	7.04	940	27	20.5	0.15	-110	7.24	7267	--	19.0	**	-147	--	--	--	--	--	--
OS-MW-10P	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.10	832	--	16.7	**	-106
PMW-3P	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.39	860	--	17.3	**	-1
TMW-1P	7.28	1193	31	17.2	1.46	49	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TMW-2P	6.94	1342	47	17.8	0.11	-227	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MINIMUM	*6.94*	*853*	*25*	*17.2*	*0.11*	*-227*	*7.03*	*940*	*5*	*17.3*	*0.03*	*-110*	*7.24*	*706*	*0*	*16.2*	*0.00*	*-147*	*7.10*	*832*	*0*	*16.7*	*0.00*	*-106*
MAXIMUM	*7.28*	*1342*	*47*	*18.5*	*1.46*	*49*	*7.15*	*1500*	*27*	*20.5*	*0.15*	*-12*	*7.75*	*7267*	*0*	*19.0*	*0.00*	*102*	*7.39*	*860*	*0*	*17.3*	*0.00*	*-1*
AVERAGE	*7.18*	*1173*	*34*	*17.8*	*0.57*	*-41*	*7.07*	*1183*	*18*	*18.6*	*0.08*	*-67*	*7.47*	*2978*	*0*	*17.9*	*0.00*	*-13*	*7.25*	*846*	*0*	*17.0*	*0.00*	*-54*
USG																								
AF-2S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
AF-4S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.86	829	--	15.8	**	-140
AF-5S	7.28	1004	7	17.6	0.20	-145	7.23	1100	7	17.5	0.01	-218	7.42	985	--	16.3	**	-116	--	--	--	--	--	--
AF-7S	7.27	718	11	18.3	0.16	-168	7.08	894	40	19.1	0.08	-220	7.39	820	--	18.6	**	-56	--	--	--	--	--	--
GM-10S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-222	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.22	755	--	16.9	**	-139
OS-MW-1S	7.13	721	7	17.6	0.10	-128	6.91	845	18	17.2	0.18	-191	7.27	939	--	16.7	0.87	-180	--	--	--	--	--	--
OS-MW-4S	--	--	--	--	--	--	6.50	1150	69	17.4	**	-184	6.61	1156	--	17.4	0.87	-186	--	--	--	--	--	--
OS-MW-10S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.62	2409	--	17.4	**	-70
OS-MW-11S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.67	1106	--	15.3	**	-139
OS-MW-12S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.60	1463	--	14.5	**	-132
OS-MW-13S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
PMW-3S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.40	741	--	17.4	**	-114
TMW-1S	7.42	749	26	18.2	0.14	-173	6.96	1020	57	18.8	0.18	-204	7.07	1881	--	18.2	**	-132	--	--	--	--	--	--
TMW-2S	7.40	889	28	17.7	0.16	-174	7.02	989	68	18.2	0.71	-203	7.29	1004	--	17.3	0.00	-161	--	--	--	--	--	--
MINIMUM	*7.13*	*718*	*7*	*17.6*	*0.10*	*-174*	*6.50*	*845*	*7*	*17.2*	*0.01*	*-220*	*6.61*	*820*	*0*	*16.3*	*0.00*	*-186*	*6.62*	*741*	*0*	*14.5*	*0.00*	*-140*
MAXIMUM	*7.42*	*1004*	*28*	*18.3*	*0.20*	*-128*	*7.23*	*1150*	*69*	*19.1*	*0.71*	*-184*	*7.42*	*1881*	*0*	*18.6*	*0.87*	*-56*	*8.22*	*2409*	*0*	*17.4*	*0.00*	*-70*
AVERAGE	*7.30*	*816*	*16*	*17.9*	*0.15*	*-158*	*6.95*	*1000*	*43*	*18.0*	*0.23*	*-203*	*7.18*	*1131*	*0*	*17.4*	*0.58*	*-138*	*7.56*	*1217*	*0*	*16.2*	*0.00*	*-122*
LSG																								
AF-5D	--	--	--	--	--	--	7.09	1030	47	15.9	0.00	-208	7.45	946	--	14.7	**	-130	--	--	--	--	--	--
AF-7D	--	--	--	--	--	--	7.15	901	66	17.1	0.18	-196	7.48	880	--	15.0	**	-169	--	--	--	--	--	--
AF-21D	--	--	--	--	--	--	7.06	754	68	17.7	0.22	-225	7.10	761	--	17.2	0.41	-203	--	--	--	--	--	--
OS-MW-1D	7.25	693	49	17.3	0.10	-139	7.00	838	75	16.7	0.28	-201	7.40	811	--	15.7	0.90	-220	--	--	--	--	--	--
OS-MW-3D	7.18	745	7	16.9	0.30	-107	7.03	931	33	17.6	0.39	-200	7.04	932	--	17.5	0.51	-175	--	--	--	--	--	--
OS-MW-4D	--	--	--	--	--	--	6.72	927	18	16.5	**	-173	6.78	964	--	16.8	0.68	-213	--	--	--	--	--	--
OS-MW-5D	--	--	--	--	--	--	6.86	1400	48	16.1	**	-173	7.37	1224	--	14.7	1.13	-275	--	--	--	--	--	--
OS-MW-6D	--	--	--	--	--	--	6.84	1210	61	17.6	**	-206	7.84	1184	--	16.1	**	**	--	--	--	--	--	--
OS-MW-7D	--	--	--	--	--	--	7.15	901	66	17.1	0.18	-196	7.00	196	--	15.0	0.55	-168	--	--	--	--	--	--
OS-MW-8D	--	--	--	--	--	--	6.98	945	36	17.8	0.81	-223	7.53	946	--	16.2	0.56	-189	--	--	--	--	--	--
PMW-3D	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.31	611	--	14.9	**	-140
TMW-1D	7.49	743	700	17.2	0.11	-464	6.77	910	42	16.7	0.09	-199	7.35	1006	--	15.2	**	-158	--	--	--	--	--	--
TMW-2D	7.40	535	600	17.0	0.16	-567	6.93	1090	52	17.1	0.34	-188	7.32	998	--	15.4	0.00	-150	--	--	--	--	--	--
MINIMUM	*7.18*	*535*	*7*	*16.9*	*0.10*	*-567*	*6.72*	*754*	*18*	*15.9*	*0.00*	*-225*	*6.78*	*196*	*0*	*14.7*	*0.00*	*-275*	*7.31*	*611*	*0*	*14.9*	*0.00*	*-140*
MAXIMUM	*7.49*	*745*	*700*	*17.3*	*0.30*	*-107*	*7.15*	*1400*	*75*	*17.8*	*0.81*	*-173*	*7.84*	*1224*	*0*	*17.5*	*1.13*	*-130*	*7.31*	*611*	*0*	*14.9*	*0.00*	*-140*
AVERAGE	*7.33*	*679*	*339*	*17.1*	*0.17*	*-319*	*6.97*	*986*	*51*	*17.0*	*0.28*	*-199*	*7.31*	*904*	*0*	*15.8*	*0.59*	*-186*	*7.31*	*611*	*0*	*14.9*	*0.00*	*-140*

-- Not Measured
** Not Measured or included due to meter malfunction

Table 2. Groundwater Elevation Data

Aquifer	Monitoring Well	Top of Casing	July-08		October-09	
			DTW	GWE	DTW	GWE
Perched Wells	AF-2P	563.39	21.89	541.50	22.50	540.89
	AF-3P	561.82	20.48	541.34	21.11	540.71
	AF-5P	561.22	20.93	540.29	21.50	539.72
	AF-7P	561.21	21.81	539.40	22.38	538.83
	AF-23P	559.62	17.91	541.71	18.23	541.39
	AF-24P	558.89	17.55	541.34	18.12	540.77
	AF-25P	558.08	17.32	540.76	17.93	540.15
	H-221	554.37	18.38	535.99	18.59	535.78
	OS-MW1P	554.09	15.63	538.46	15.87	538.22
	OS-MW2P	557.01	17.30	539.71	17.69	539.32
	OS-MW-10P	558.57	NM		21.00	537.57
	PMW-3P	560.1	NM		21.95	538.15
	AOC PST MW-2S	559.70	16.13	543.57	17.00	542.70
	AOC LD MW1S	555.81	12.58	543.23	NM	
USG Wells	AF-2S	562.67	NM		22.79	539.88
	AF-3S	561.98	NM		22.19	539.79
	AF-4S	562.22	NM		22.63	539.59
	AF-5S	561.60	21.86	539.74	22.44	539.16
	AF-7S	562.02	22.79	539.23	23.30	538.72
	AF-9S	564.19	28.70	535.49	28.86	535.33
	GM-1	564.41	NM		20.67	543.74
	GM-3S	562.86	NM		21.65	541.21
	GM-7S	569.91	NM		24.94	544.97
	GM-10S	562.12	NM		20.80	541.32
	GM-11S	568.61	NM		28.07	540.54
	H-222	554.41	NM		18.72	535.69
	TMW-1S	561.63	22.07	539.56	22.60	539.03
	TMW-2S	560.15	24.08	536.07	24.68	535.47
	OS-MW1S	554.14	15.71	538.43	16.03	538.11
	OS-MW3S	559.88	23.13	536.75	23.66	536.22
	OS-MW4S	565.10	28.98	536.12	30.01	535.09
	OS-MW5S	576.44	43.51	532.93	44.09	532.35
	OS-MW6S	586.38	51.60	534.78	52.12	534.26
	OS-MW8S	584.33	51.81	532.52	52.71	531.62
	OS-MW-10S	558.59	NM		20.98	537.61
	OS-MW-11S	551.64	NM		13.16	538.48
	OS-MW-12S	553.24	NM		14.21	539.03
	OS-MW-13S	551.67	NM		13.51	538.16
	PMW-3S	560.12	NM		21.97	538.15
LSG Wells	AF-5D	561.66	24.35	537.31	25.02	536.64
	AF-7D	561.23	24.48	536.75	25.11	536.12
	AF-21D	559.61	23.47	536.14	24.18	535.43
	TMW-1D	562.02	25.01	537.01	25.61	536.41
	TMW-2D	559.86	23.83	536.03	24.49	535.37
	OS-MW1D	554.16	17.52	536.64	18.12	536.04
	OS-MW3D	559.91	23.84	536.07	24.48	535.43
	OS-MW4D	565.14	28.99	536.15	30.05	535.09
	OS-MW5D	560.25	32.97	527.28	33.60	526.65
	OS-MW6D	586.08	51.63	534.45	52.16	533.92
	OS-MW7D	592.09	56.75	535.34	NM	
	OS-MW8D	584.34	52.37	531.97	52.75	531.59
	PMW-3D	560.04	NM		24.41	535.63

Notes:
1) Measurements are in feet (ft).
2) DTW denotes Depth To Water.
3) GWE denotes ground water elevation (NAVD83).
4) NM denotes Not Measured.

Table 3. Sample Schedule for $\delta^{13}C$ and $\delta^{37}Cl$ Analysis

		August 2008 Sampling Event				
Zone	Well	TCE	c12DCE	VC	TCA	11DCA
LSG	AF-21D					
LSG	OS-MW-1D					
LSG	OS-MW-3D					
LSG	OS-MW-4D					
LSG	OS-MW-5D					
LSG	OS-MW-6D					
LSG	OS-MW-7D					
LSG	OS-MW-8D					
LSG	TMW-2D					

		November 2009 Sampling Event				
Zone	Well	TCE	c12DCE	VC	TCA	11DCA
Perched Aquifer	AF-7P					
Perched Aquifer	AF-24P					
Perched Aquifer	OS-MW-10P					
Perched Aquifer	PMW-3P					
USG	AF-2S					
USG	AF-4S					
USG	AF-7S					
USG	GM-10S					
USG	H-222					
USG	OS-MW-1S					
USG	OS-MW-4S					
USG	OS-MW-10S					
USG	OS-MW-11S					
USG	OS-MW-12S					
USG	OS-MW-13S					
USG	PMW-3S					
LSG	OS-MW-1D					
LSG	OS-MW-3D					
LSG	PMW-3D					

$\delta^{13}C$ data collected	
$\delta^{37}Cl$ data collected	
both $\delta^{37}Cl$ and $\delta^{13}C$ data collected	

Table 4. Summary of CVOC Concentrations and Stable Carbon Isotope Ratios - LSG - August 2008

well	Sampling date	TCE			cis-DCE			VC			1,1,1-TCA			1,1-DCA		
		conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)
LSG																
OS-MW-1D	Aug-08				930	-19.6		228	-23.5							
OS-MW-3D	Aug-08	550	-18.4		590	-27.4										
OS-MW-4D	Aug-08				35	-24.5		18	-13.8							
OS-MW-5D	Aug-08				237	-21.6		28	-23.5							
OS-MW-6D	Aug-08				68	-5.1		173	-31.4							
OS-MW-8D	Aug-08							33	-15.4							
TMW-2D	Aug-08	99	-16.4		192	-22.9										

NM Not Measured
ND Not Detected
BDL Below Detection Limit

Table 5. Summary of CVOC Concentrations and Stable Carbon and Chlorine Isotope Ratios - November 2009

well	Sampling date	TCE			cis-DCE			VC			1,1,1-TCA			1,1-DCA		
		conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{37}Cl$ (‰)
Perched																
AF-7P	Nov-09	800	-25	1.35	30	-24.9	3.94	ND	BDL		930	-28.1	1.82	48	-31.4	6.33
AF-24P	Nov-09	280	-23.7	1.68	37	-26.9	3.67	1	-34.2		330	-25.7	2.95	32	-27.8	-4.61
OS-MW-10P	Nov-09	270	-23.2	1.93	29	-19.5	6.64	5	BDL		370	-25.4	3.44	59	-31.2	7.32
PMW-3P	Nov-09	420	-20.6	2.07	13	-17.4	6.17	ND	BDL		230	-25.8	3.51	22	-32.4	6.98
USG																
AF-2S	Nov-09	63	-22	1.18	33	-14.5	5.09	11	-30.2		6	BDL		11	-20.1	9.88
AF-4S	Nov-09	50	-21.5	1.8	140	-16.4	5.02	59	-19		29	-13.7	5.27	25	-26.8	6.88
AF-7S	Nov-09	ND	BDL		500	-16.5	4.82	660	-34.1	-0.63	ND	BDL		15	-12.3	10.46
GM-10S	Nov-09	ND	BDL		ND	BDL		ND	BDL		13	-24.6	2.77	9	-26.4	11.28
H-222	Nov-09	39	-19.4	1.97	120	-16.8	5.13	34	-16.8	4.62	14	-14.3	5.51	58	-23	10.59
OS-MW-1S	Nov-09	ND	BDL		3000	-21	3.93	530	-35.3	-2.03	ND	BDL		55	-2.9	-5.67
OS-MW-4S	Nov-09	ND	BDL		18	-17.4	5.02	20	-39.8	-1.48	ND	BDL		ND	BDL	
OS-MW-10S	Nov-09	95	-20.8	2.18	15	BDL	6	9	BDL		310	-24.9	4.95	18	-30.8	6.77
OS-MW-11S	Nov-09	25	-22.4		460	-21.8	3.95	18	-13.7		ND	BDL		44	-37.2	6.58
OS-MW-12S	Nov-09	ND	BDL		220	-15.5	5.34	13	BDL		ND	BDL		69	-20.6	5.63
OS-MW-13S	Nov-09	7.9	BDL	2.45	360	-17.2	4.34	87	-31.9	0.59	ND	BDL		33	-19.6	10.37
PMW-3S	Nov-09	38	-16.1	2.7	59	-17.5	6.08	25	-19.2		96	-8.7	19.13	100	-23.8	11.29
LSG																
OS-MW-1D	Nov-09	ND	BDL		790	-20.5	4.29	210	-30.9	1.84	ND	BDL		18	-30.9	2.44
OS-MW-3D	Nov-09	97	-9.92	6.19	820	-25.9	4.97	39	-27.9		ND	BDL		6	BDL	
PMW-3D	Nov-09	130	-22	1.96	46	-17.6	6.81	17	-6.6		210	-17.9	7.34	97	-27.8	8.78

NM Not Measured
ND Not Detected
BDL Below Detection Limit

Table 6. Summary of Interwell Groundwater Velocity Calculations

Aquifer/Location	K	Porosity	Hydraulic Gradient	Interwell Groundwater Velocity
	ft/day	n	ft/ft	ft/day
Perched				
AF-7P to PMW-3P	400	0.25	0.0027	4.3
AF-7P to OSMW-10P	400	0.25	0.0026	4.1
USG				
AF-2S to AF-4S	850	0.25	0.0013	4.3
AF-2S to PMW-3S	850	0.25	0.0014	4.7
AF-2S to H-222	850	0.25	0.0021	7.2
AF-4S to H-222	850	0.25	0.0022	7.6
AF-4S to OSMW-13S	850	0.25	0.0015	5.2
AF-7S to OSMW-10S	850	0.25	0.0022	7.6
AF-7S to H-222	850	0.25	0.0031	10.5
OSMW-10S to H-222	850	0.25	0.0039	13.4
LSG				
OSMW-3D to TMW-2D	125	0.25	0.0008	0.4

Table 7. Summary of Biodegradation Rate Calculations and Results

PERCHED AQUIFER $\delta^{13}C$ (‰) VALUES

well	TCE															Published Values	
	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{13}C_o$ (‰)	ε_{max}	ε_{min}	ε_{avg}	fraction remaining (f_{max})	fraction remaining (f_{min})	fraction remaining (f_{avg})	Average groundwater velocity (ft/day)	Distance from AF-7P (ft)	Average travel time (days)	Rate of Degradation (λ_{min}) (per day)	Rate of Degradation (λ_{max}) (per day)	Rate of Degradation (λ_{avg}) (per day)	λ_{min} (per day)	λ_{max} (per day)
AF-7P	800	-25	-25	-22.9	-2.5	-12.0											
PMW-3P	420	-20.6					0.822	0.165	0.687	4.3	252	59	0.0034	0.0307	0.0064	0.0001	0.04
OS-MW-10P	270	-23.2					0.923	0.478	0.858	4.1	491	120	0.0007	0.0062	0.0013	0.0001	0.04
AF-7P	800	-25	-29	-22.9	-2.5	-12.0	0.836	0.193	0.710		0						
PMW-3P	420	-20.6					0.687	0.032	0.488	4.3	252	59	0.0064	0.0588	0.0122	0.0001	0.04
OS-MW-10P	270	-23.2					0.771	0.092	0.609	4.1	491	120	0.0022	0.0199	0.0041	0.0001	0.04

PERCHED AQUIFER $\delta^{37}Cl$ (‰) VALUES

well	TCE															Published Values	
	conc (µg/l)	$\delta^{37}Cl$ (‰)	$\delta^{37}Cl_o$ (‰)	ε_{max}	ε_{min}	ε_{avg}	fraction remaining (f_{max})	fraction remaining (f_{min})	fraction remaining (f_{avg})	Average groundwater velocity (ft/day)	Distance from AF-7P (ft)	Average travel time (days)	Rate of Degradation (λ_{min}) (per day)	Rate of Degradation (λ_{max}) (per day)	Rate of Degradation (λ_{avg}) (per day)	λ_{min} (per day)	λ_{max} (per day)
AF-7P	800	1.35	1.35	-30	-5.5	-11.7											
PMW-3P	420	2.07					0.976	0.877	0.940	4.3	252	59	0.0004	0.0022	0.0010	0.0001	0.04
OS-MW-10P	270	1.93					0.981	0.900	0.952	4.1	491	120	0.0002	0.0009	0.0004	0.0001	0.04
AF-7P	800	1.35	0.9	-30	-5.5	-11.7	0.985	0.922	0.962		0						
PMW-3P	420	2.07					0.962	0.809	0.905	4.3	252	59	0.0007	0.0036	0.0017	0.0001	0.04
OS-MW-10P	270	1.93					0.966	0.829	0.916	4.1	491	120	0.0003	0.0016	0.0007	0.0001	0.04

Table 7. Summary of Biodegradation Rate Calculations and Results (cont.)

USG AQUIFER $\delta^{13}C$ (‰) VALUES

well	TCE															Published Values	
	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{13}C_o$ (‰)	ε_{max}	ε_{min}	ε_{avg}	fraction remaining (f_{max})	fraction remaining (f_{min})	fraction remaining (f_{avg})	Average groundwater velocity (ft/day)	Distance from AF-2S (ft)	Average travel time (days)	Rate of Degradation (λ_{min}) (per day)	Rate of Degradation (λ_{max}) (per day)	Rate of Degradation (λ_{avg}) (per day)	λ_{min} (per day)	λ_{max} (per day)
AF-2S	63	-22	-22	-22.9	-2.5	-12.0											
AF-4S	50	-21.5					0.978	0.815	0.958	4.3	228	53	0.0004	0.0039	0.0008	0.0001	0.04
PMW-3S	38	-16.1					0.769	0.090	0.606	4.7	1245	265	0.0010	0.0091	0.0019	0.0001	0.04
H-222	39	-19.4					0.891	0.346	0.802	7.2	1966	273	0.0004	0.0039	0.0008	0.0001	0.04
AF-2S	63	-22	-29	-22.9	-2.5	-12.0	0.731	0.057	0.550		0						
AF-4S	50	-21.5					0.715	0.046	0.527	4.3	228	53	0.0063	0.0580	0.0121	0.0001	0.04
PMW-3S	38	-16.1					0.562	0.005	0.333	4.7	1245	265	0.0022	0.0199	0.0042	0.0001	0.04
H-222	39	-19.4					0.651	0.020	0.440	7.2	1966	273	0.0016	0.0144	0.0030	0.0001	0.04

USG AQUIFER $\delta^{13}C$ (‰) VALUES

well	TCE															Published Values	
	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{13}C_o$ (‰)	ε_{max}	ε_{min}	ε_{avg}	fraction remaining (f_{max})	fraction remaining (f_{min})	fraction remaining (f_{avg})	Average groundwater velocity (ft/day)	Distance from AF-4S (ft)	Average travel time (days)	Rate of Degradation (λ_{min}) (per day)	Rate of Degradation (λ_{max}) (per day)	Rate of Degradation (λ_{avg}) (per day)	λ_{min} (per day)	λ_{max} (per day)
AF-4S	50	-21.5	-21.5	-22.9	-2.5	-12.0											
H-222	39	-19.4					0.911	0.424	0.836	7.6	1743	229	0.0004	0.0037	0.0008	0.0001	0.04
AF-4S	50	-21.5	-29	-22.9	-2.5	-12.0	0.715	0.046	0.527								
H-222	39	-19.4					0.651	0.020	0.440	7.6	1743	229	0.0019	0.0172	0.0036	0.0001	0.04

Table 7. Summary of Biodegradation Rate Calculations and Results (cont.)

USG AQUIFER $\delta^{37}Cl$ (‰) VALUES

well	TCE															Published Values	
	conc (µg/l)	$\delta^{37}Cl$ (‰)	$\delta^{37}Cl_o$ (‰)	ε_{max}	ε_{min}	ε_{avg}	fraction remaining (f_{max})	fraction remaining (f_{min})	fraction remaining (f_{avg})	Average groundwater velocity (ft/day)	Distance from AF-4S (ft)	Average travel time (days)	Rate of Degradation (λ_{min}) (per day)	Rate of Degradation (λ_{max}) (per day)	Rate of Degradation (λ_{avg}) (per day)	λ_{min} (per day)	λ_{max} (per day)
AF-4S	50	1.8	1.8	-30	-5.5	-11.7											
H-222	39	1.97					0.994	0.970	0.986	7.6	1743	229	0.00002	0.0001	0.0001	0.0001	0.04
AF-4S	50	1.8	0.9	-30	-5.5	-11.7	0.970	0.849	0.926		0						
H-222	39	1.97					0.965	0.823	0.913	7.6	1743	229	0.0002	0.0008	0.0004	0.0001	0.04

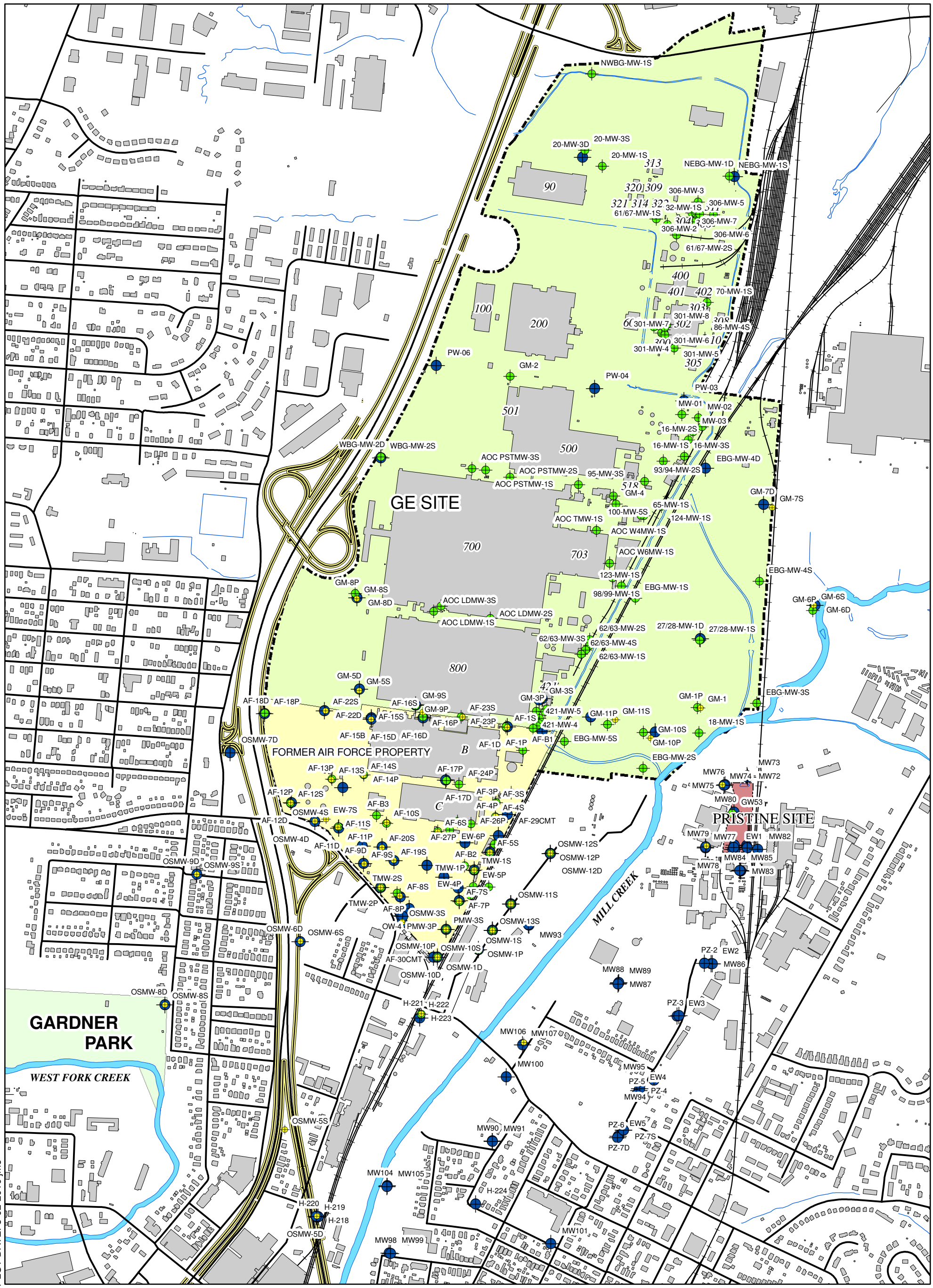
USG AQUIFER $\delta^{13}C$ (‰) VALUES

well	TCE															Published Values	
	conc (µg/l)	$\delta^{13}C$ (‰)	$\delta^{13}C_o$ (‰)	ε_{max}	ε_{min}	ε_{avg}	fraction remaining (f_{max})	fraction remaining (f_{min})	fraction remaining (f_{avg})	Average groundwater velocity (ft/day)	Distance from AF-4S (ft)	Average travel time (days)	Rate of Degradation (λ_{min}) (per day)	Rate of Degradation (λ_{max}) (per day)	Rate of Degradation (λ_{avg}) (per day)	λ_{min} (per day)	λ_{max} (per day)
OS-MW-10S	95	-20.8	-20.8	-22.9	-2.5	-12.0											
H-222	39	-19.4					0.940	0.565	0.888	13.4	487	36	0.0017	0.0157	0.0033	0.0001	0.04
OS-MW-10S	95	-20.8	-29	-22.9	-2.5	-12.0	0.693	0.035	0.496		0						
H-222	39	-19.4					0.651	0.020	0.440	13.4	487	36	0.0118	0.1083	0.0226	0.0001	0.04

FIGURES

FIGURE 1

I:\10361\44006\DOCS\REPEORTS\ISO\MXDS\009-SITE PLAN.MXD



PLOT DATE: 8-02-2010 jmo

LEGEND

- PERCHED WELL LOCATION
- USG WELL LOCATION
- LSG WELL LOCATION

GE
EVENDALE, OHIO

SITE PLAN

N

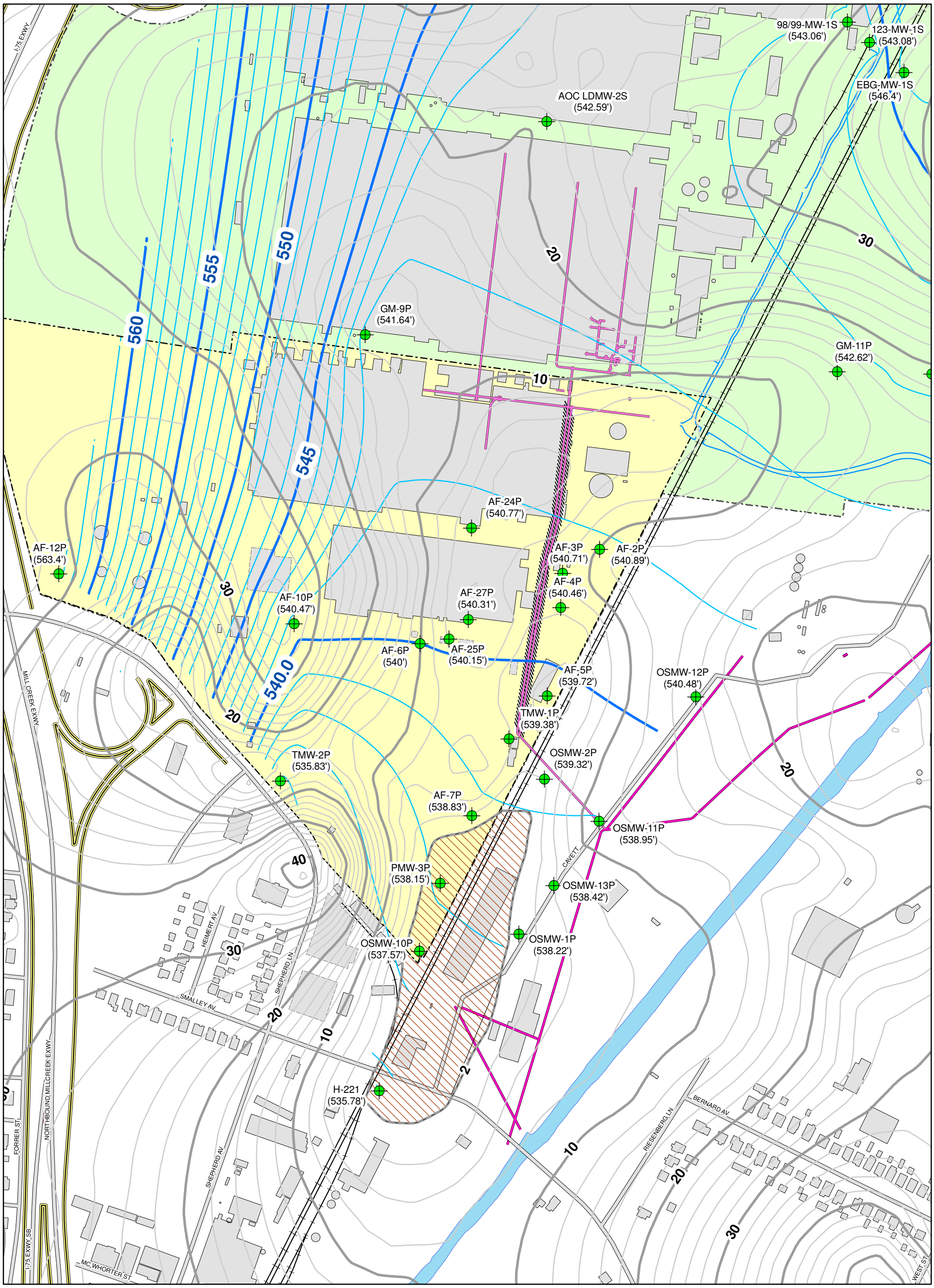
0 500 1,000 1,500 2,000
Feet

O'BRIEN & GERE ENGINEERS, INC.

10361\44006\REP\ISO\009
JUNE 2010

FIGURE 2

I:\PROJ\10361\44006\REP\ISOTOPE REP\MXDS\001.MXD



PLOT DATE: 6-15-2010 ajf

LEGEND

- (537.75') PERCHED MONITORING WELLS WITH GROUNDWATER ELEVATION
- 540.0 GROUNDWATER CONTOUR (OCTOBER 2009)
- PERCHED/USG COMMUNICATION AREA
- 10 UPPER CONFINING LAYER THICKNESS ISOCONTOUR (FEET)
- SANITARY SEWER
- SANITARY SEWER SLIP LINE

GE
EVENDALE, OHIO

PERCHED AQUIFER GROUNDWATER FLOW MAP

0 250 500 750 1,000
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

44006/REP/ISO/MXDS/001

JUNE 2010

FIGURE 3

I:\10361\44006\REP\ISOTOPE\MXDS\002.MXD

GM-8S (538.29')
GM-3S (541.21')
GM-9S (540.29')
GM-11S (540.54')
GM-10S (541.32')
AF-2S (539.88')
AF-4S (539.59')
AF-6S (539.32')
AF-5S (539.16')
AF-12S (535.05')
OSMW-4S (535.09')
AF-10S (535.85')
AF-11S (535.32')
AF-20S (535.57')
AF-9S (535.33')
AF-19S (535.82')
OSMW-12S (539.03')
OSMW-9S (533.11')
TMW-2S (535.47')
TMW-1S (539.03')
AF-8S (535.82')
AF-7S (538.72')
OSMW-3S (536.22')
OSMW-11S (538.48')
PMW-3S (538.15')
OSMW-13S (538.16')
OSMW-6S (534.26')
OSMW-1S (538.11')
OSMW-10S (537.61')
OSMW-8S (531.93')
H-222 (535.69')
MW107 (537.11')
OSMW-5S (532.35')
LINDY AV
CHAMBERLAIN ST
BYRD AV
MCINTYRE ST
LOCKLAND RD
STEFFENS AV
SIMMONS AV
BEHLES ST
SCHUMARD AV
I-75 EXWY
CATHERINE AV
MILL CREEK EXWY
JONTE AV
HOME AV
WESTVIEW AV
PERSHING AV
HEIMERT AV
SMALLEY AV
SHEPHERD LN
HIGHLANDS AV
N.COOPER AV
EPPERDING DR
BACON ST
I-75 EXWY-SB
MC.WHORTER ST
SHEPHERD AV
MOOCK AV
FORRER ST
E.FORRER ST
NORTHBOUND MILL CREEK EXWY
CAVETT
BERNARD AV
RIESENBERG LN
WEST ST
MCWORTER ST
FENTON AV
KOENIG AV
JEFFERSON AV
BROWN ST
MECHANIC ST
CARSON ST
BONNELL ST
COLUMBIA ST
MARKET ST
PLEASANT ST
540.0
535.0
20
30
40
10
50
2

PLOT DATE: 6-15-2010 ajf

LEGEND

(532.35') USG MONITORING WELLS WITH GROUNDWATER ELEVATION

PERCHED/USG COMMUNICATION AREA

540.0 GROUNDWATER CONTOUR (OCTOBER 2009)

10 UPPER CONFINING LAYER THICKNESS ISOCONTOUR (FEET)

GE
EVENDALE, OHIO

USG AQUIFER GROUNDWATER FLOW MAP

0 250 500 750 1,000
Feet

N

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GE\4006\ISO\002
JUNE 2010

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GM-8D (538.42')
GM-9D (537.25')
GM-3D (539.26')
27/28-MW-2D (538.66')
PMW-4D (536.79')
AF-12D (535.05')
OSMW-4D (535.09')
AF-11D (535.31')
AF-20D (535.6')
AF-21D (535.43')
AF-19D (535.65')
AF-9D (535.32')
PMW-2D (536.84')
AF-5D (536.64')
TMW-1D (536.41')
OSMW-12D (537.30')
OSMW-12DD (537.30')
OSMW-9D (533.093')
AF-8D (535.37')
AF-7D (536.12')
TMW-2D (535.37')
OSMW-11DD (536.44')
OSMW-11D (536.37')
OSMW-3D (535.43')
MW93 (536.5')
MW92 (536.48')
PMW-3D (535.63')
OSMW-13D (536.09')
OSMW-6D (533.92')
OSMW-1D (536.04')
OSMW-10D (535.48')
OSMW-8D (531.89')
H-223 (534.98')
MW106 (535.76')
(W100 (528.92')
PZ-4 (528.53')
PZ-5 (528.4')
PZ-7S (527.4')
PZ-6 (527.2')
PZ-7D (527.27')
MW90 (528.31')
MW91 (528.31')
MW104 (526.94')
MW105 (526.83')
H-218 (526.61')
H-220 (525.95')
OSMW-5D (526.65')
H-224 (526.97')
MW99 (526.88')
MW98 (526.9')
MW101 (527.29')

CHAMBERLAIN ST
BYRD AV
STEFFENS AV
SIMMONS AV
BEHLES ST
SCHUMARD AV
CATHERINE AV
HOME AV
WESTVIEW AV
PERSHING AV
HIGHLANDS AV
EPPERDING DR
BACON ST
MOOCK AV
JONTE AV
WYOMING AV
CROSS ST
MCWORTER ST
CARSON ST
VINE ST
SMALLEY AV
HEIMERT AV
SHEPHERD LN
SHEPHERD AV
MILL ST
FENTON AV
KOENIG AV
BROWN ST
COLUMBIA ST
MECHANIC ST
MARKET ST
WALNUT ST
HALKER ST
BONNELL ST
BERNARD AV
WEST ST
JEFFERSON AV
CAVETT
RIESENBERG LN
LOCKLAND RD
MCINTYRE ST
MILL CREEK EXWY
I-75 EXWY
FORRER ST
S COOPER AV
N COOPER AV
E FORRER ST
I-75 EXWY-SB
NORTHBOUND MILL CREEK EXWY
MC WHORTER ST

540.0
535.0
530.0
60
70
50
40
30
20
10
2

PLOT DATE: 8-02-2010 jmo

LEGEND

(526.65') LSG MONITORING WELLS WITH GROUNDWATER ELEVATION

USG/LSG COMMUNICATION AREA

540.0 GROUNDWATER CONTOUR (OCTOBER 2009)

10 LOWER CONFINING LAYER THICKNESS ISOCONTOUR (FEET)

GE
EVENDALE, OHIO

LSG AQUIFER GROUNDWATER FLOW MAP

0 250 500 750 1,000
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

44006\REP\ISO\MXDS\003
JUNE 2010

FIGURE 5

i\10361\44006\REP\ISO\MXDS\004.MXD

GM-8P
AOC LDMW-1S
300 ug/l
AOC LDMW-3S
AOC LDMW-2S
98/99-MW-1S
123-MW-1S
EBG-MW-1S
62/63-MW-2S
62/63-MW-1S
62/63-MW-3S
62/63-MW-4S
GM-9P
AF-16P
AF-23P
350 ug/l
421-MW-5
GM-3P
421-MW-1
421-MW-6
421-MW-3
421-MW-2
421-MW-4
GM-11P
GM-10P
AF-1P
EBG-MW-5S
AF-B1
EBG-MW-2S
560
555
550
545
540
AF-14P
AF-13P
AF-17P
AF-24P
280 ug/l
δ 13 C -23.7
δ 37 Cl 1.68
AF-2P
43 ug/l
AF-12P
AF-3P
130 ug/l
AF-B3
AF-4P
AF-10P
AF-27P
AF-26P
AF-11P
AF-6P
AF-25P
240 ug/l
AF-5P
380 ug/l
AF-B2
TMW-1P
TMW-2P
not detected
AF-7P
800 ug/l
δ 13 C -25
δ 37 Cl 1.35
EW-5P
OSMW-2P
72 ug/l
AF-8P
EW-4P
OSMW-12P
3.8 ug/l
OSMW-11P
not detected
OSMW-13P
not detected
PMW-3P
430 ug/l
δ 13 C -20.6
δ 37 Cl 2.07
OSMW-1P
not detected
OSMW-10P
280 ug/l
δ 13 C -23.2
δ 37 Cl 1.93
H-221
75 ug/l
I-75 EXWY
MILL CREEK EXWY
SHEPHERD LN
HEIMERT AV
SMALLEY AV
NORTHBOUND MILLCREEK EXWY
FORRER ST
I-75 EXWY SB
SHEPHERD AV
MC.WHORTER ST
CAVETT
RIESENBERG LN

NOTE:
THE MAGNITUDE OF TCE FOR THE SAMPLED WELLS IS DENOTED BY THE SIZE AND COLOR OF THE HIGHLIGHT SURROUNDING THE WELL SYMBOL.
<5 ug/l
>5ug/l and <50 ug/l
>50 ug/l and <500 ug/l
>500 ug/l

PLOT DATE: 6-15-2010 ajf

LEGEND

PERCHED MONITORING WELLS

540.0 GROUNDWATER CONTOUR (OCTOBER 2009)

OS-MW10P
280 ug/l
δ13C -23.2
δ37Cl 1.93
MONITORING WELL ID
TCE CONCENTRATION (ug/l) (NOV 2009)
δ13 CARBON VALUE (‰ V-PDB)
δ37 CHLORINE VALUE (‰ SMOC)

PERCHED/USG COMMUNICATION AREA

GE
EVENDALE, OHIO

PERCHED AQUIFER
δ13 CARBON AND δ37 CHLORINE OF TCE

0 250 500 750 1,000
Feet

N

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44006\REP\ISO\004

JUNE 2010

FIGURE 6

I:\10361\44006\REP\ISO\MXD\005.MXD

GM-8P
AOC LDMW-1S
430 ug/l
AOC LDMW-3S
AOC LDMW-2S
98/99-MW-1S
123-MW-1S
EBG-MW-1S
62/63-MW-2S
62/63-MW-1S
62/63-MW-3S
62/63-MW-4S
GM-9P
AF-16P
AF-23P
370 ug/l
421-MW-5
GM-3P
421-MW-1
421-MW-6
421-MW-3
421-MW-2
421-MW-4
AF-1P
GM-11P
GM-10P
EBG-MW-5S
AF-B1
EBG-MW-2S
AF-14P
AF-13P
AF-17P
AF-24P
330 ug/l
δ 13C -25.7
δ 37Cl 2.95
AF-2P
1.8 ug/l
AF-12P
AF-3P
53 ug/l
AF-B3
AF-27P
AF-4P
AF-10P
AF-26P
AF-11P
AF-6P
AF-25P
280 ug/l
AF-5P
140 ug/l
OSMW-12P
4.0 ug/l
AF-B2
TMW-1P
TMW-2P
not detected
AF-8P
AF-7P
790 ug/l
δ 13C -28.1
δ 37Cl 1.82
EW-5P
OSMW-2P
13 ug/l
EW-4P
OSMW-11P
not detected
PMW-3P
240 (ug/l)
δ 13C -25.8
δ 37Cl 3.51
OSMW-13P
not detected
OSMW-10P
400 (ug/l)
δ 13C -25.4
δ 37Cl 3.44
OSMW-1P
not detected
H-221
47 ug/l
560
555
550
545
540
I-75 EXWY
MILL CREEK EXWY
NORTHBOUND MILLCREEK EXWY
I-75 EXWY SB
SHEPHERD LN
HEIMERT AV
SMALLEY AV
FORRER ST
MC WHORTER ST
SHEPHERD AV
CAVETT
RIESENBERG LN

NOTE:
THE MAGNITUDE OF 1,1,1-TCA FOR THE SAMPLED WELLS IS DENOTED BY THE SIZE AND COLOR OF THE HIGHLIGHT SURROUNDING THE WELL SYMBOL.
<20 ug/l
>20 ug/l and <200 ug/l
>200 ug/l and <500 ug/l
>500 ug/l

PLOT DATE: 2-22-2010 jmo

LEGEND

- PERCHED MONITORING WELLS
- 540.0 — GROUNDWATER CONTOUR (OCTOBER 2009)
- OS-MW10P / 43 ug/l / δ13 C -20.7 / δ37 Cl 1.93 — MONITORING WELL ID; 1,1,1- TCA CONCENTRATION (ug/l) (NOV 2009); δ13 CARBON VALUE (‰ V-PDB); δ37 CHLORINE VALUE (‰ SMOC)
- PERCHED/USG COMMUNICATION AREA

GE
EVENDALE, OHIO

PERCHED AQUIFER

δ13 CARBON AND δ37 CHLORINE OF 1,1,1- TCA

0 250 500 750 1,000
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

GEAE\ZMXDs\004
FEBRUARY 2010

FIGURE 7

i:\10361\44006\REP\ISO\MXDS\006.MXD

GM-8S
GM-5S
GM-9S
not detected
GM-3S
3.1 ug/l
AF-22S
AF-16S
AF-23S
AF-15S
AF-1S
GM-11S
not detected
GM-10S
not detected
δ^{13}C below detection
540
AF-14S
AF-13S
AF-2S
63 ug/l
δ^{13}C -22.0
δ^{37}Cl 1.18
AF-12S
AF-3S
not detected
AF-10S
AF-11S
AF-6S
AF-4S
58 ug/l
δ^{13}C -21.5
δ^{37}Cl 1.80
OSMW-4S
not detected
δ^{13}C below detection
AF-20S
AF-19S
AF-5S
530 ug/l
OSMW-12S
not detected
δ^{13}C below detection
AF-9S
not detected
OSMW-9S
not detected
TMW-2S
not detected
TMW-1S
not detected
AF-8S
AF-7S
not detected
δ^{13}C below detection
OSMW-11S
25 ug/l
δ^{13}C -22.4
OSMW-3S
not detected
PMW-3S
38 ug/l
δ^{13}C -16.1
δ^{37}Cl 2.70
OSMW-6S
2.1 ug/l
OSMW-13S
7.9 ug/l
δ^{13}C below detection
δ^{37}Cl 2.45
OSMW-10S
95 ug/l
δ^{13}C -20.8
δ^{37}Cl 2.18
OSMW-1S
not detected
δ^{13}C below detection
535
OSMW-8S
not detected
H-222
39 ug/l
δ^{13}C -19.4
δ^{37}Cl 1.97
MW107
OSMW-5S
not detected
LINDY AV
CHAMBERLAIN ST
BYRD AV
MCINTYRE ST
LOCKLAND RD
STEFFENS AV
SIMMONS AV
BEHLES ST
SCHUMARD AV
I-75 EXWY
MILL CREEK EXWY
CATHERINE AV
JONTE AV
HOME AV
WESTVIEW AV
PERSHING AV
HIGHLANDS AV
N COOPER AV
EPPERDING DR
BACON ST
MOOCK AV
FORRER ST
E FORRER ST
I-75 EXWY SB
NORTHBOUND MILLCREEK EXWY
MC WHORTER ST
SHEPHERD AV
HEMMERT AV
SMALLEY AV
SHEPHERD LN
CAVETT
RIESENBERG LN
BERNARD AV
MCWORTER ST
KOENIG AV
FENTON AV
JEFFERSON AV
BROWN ST
CARSON ST
MECHANIC ST

NOTE:

THE MAGNITUDE OF TCE FOR THE SAMPLED WELLS IS DENOTED BY THE SIZE AND COLOR OF THE HIGHLIGHT SURROUNDING THE WELL SYMBOL.

- <5 ug/l
- >5ug/l and <50 ug/l
- >50 ug/l and <500 ug/l
- >500 ug/l

PLOT DATE: 6-15-2010 ajf

LEGEND

- USG MONITORING WELLS
- 540.0 — GROUNDWATER CONTOUR (OCTOBER 2009)
- OS-MW10S / 95 ug/l / δ^{13}C -20.8 / δ^{37}Cl 2.18 — MONITORING WELL ID; TCE CONCENTRATION (ug/l) (NOV 2009); δ^{13} CARBON VALUE ($^0/_{00}$ V-PDB); δ^{37} CHLORINE VALUE ($^0/_{00}$ SMOC)
- USG/LSG COMMUNICATION AREA

GE
EVENDALE, OHIO

USG AQUIFER

δ^{13} CARBON AND δ^{37} CHLORINE OF TCE

0 250 500 750 1,000
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

44006\REP\ISO\MXD\006
JUNE 2010

FIGURE 8

i\10361\44006\REP\ISO\MXDS\007.MXD

GM-8S
GM-5S
AF-22S
AF-16S
AF-23S
GM-9S
not detected
AF-1S
GM-3S
1.8 ug/l
AF-15S
GM-11S
not detected
540
GM-10S
13 ug/l
$\delta^{13}C$ -24.6
$\delta^{37}Cl$ 2.77
AF-14S
AF-13S
AF-2S
6.1 ug/l
$\delta^{13}C$ below detection
AF-12S
AF-3S
not detected
AF-10S
AF-11S
AF-6S
AF-4S
29 ug/l
$\delta^{13}C$ -13.7
$\delta^{37}Cl$ 5.27
OSMW-4S
not detected
$\delta^{13}C$ below detection
AF-20S
AF-19S
AF-5S
110 ug/l
OSMW-12S
not detected
$\delta^{13}C$ below detection
AF-9S
not detected
OSMW-9S
not detected
TMW-1S
not detected
TMW-2S
not detected
AF-8S
AF-7S
not detected
$\delta^{13}C$ below detection
OSMW-11S
not detected
$\delta^{13}C$ below detection
OSMW-3S
not detected
PMW-3S
100 ug/l
$\delta^{13}C$ -8.7
$\delta^{37}Cl$ 19.13
OSMW-13S
not detected
$\delta^{13}C$ below detection
OSMW-6S
not detected
OSMW-1S
not detected
$\delta^{13}C$ below detection
OSMW-10S
330 ug/l
$\delta^{13}C$ -24.9
$\delta^{37}Cl$ 4.95
OSMW-8S
not detected
H-222
14 ug/l
$\delta^{13}C$ -14.3
$\delta^{37}Cl$ 5.51
535
MW107
OSMW-5S
not detected

LINDY AV
CHAMBERLAIN ST
BYRD AV
MCINTYRE ST
LOCKLAND RD
STEFFENS AV
SIMMONS AV
BEHLES ST
SCHUMARD AV
I-75 EXWY
CATHERINE AV
MILL CREEK EXWY
JONTE AV
HOME AV
WESTVIEW AV
PERSHING AV
HEIMERT AV
SHEPHERD LN
SMALLEY AV
HIGHLANDS AV
N COOPER AV
EPPERDING DR
BACON ST
I-75 EXWY SB
MC WHORTER ST
MOOCK AV
FORRER ST
E FORRER ST
NORTHBOUND MILLCREEK EXWY
SHEPHERD AV
CAVETT
RIESENBERG LN
BERNARD AV
MCWORTER ST
KOENIG AV
FENTON AV
CARSON ST
JEFFERSON AV
BROWN ST
MECHANIC ST

NOTE:
THE MAGNITUDE OF 1,1,1-TCA FOR THE SAMPLED WELLS IS DENOTED BY THE SIZE AND COLOR OF THE HIGHLIGHT SURROUNDING THE WELL SYMBOL.
- <20 ug/l
- >20 ug/l and <200 ug/l
- >200 ug/l and <500 ug/l
- >500 ug/l

PLOT DATE: 6-15-2010 ajf

LEGEND

- USG MONITORING WELLS
- 540.0 — GROUNDWATER CONTOUR (OCTOBER 2009)
- OS-MW10S / 95 ug/l / $\delta^{13}C$ -20.8 / $\delta^{37}Cl$ 2.18 — MONITORING WELL ID; 1,1,1-TCA CONCENTRATION (ug/l) (NOV 2009); δ^{13} CARBON VALUE ($^0/_{00}$ V-PDB); δ^{37} CHLORINE VALUE ($^0/_{00}$ SMOC)
- USG/LSG COMMUNICATION AREA

GE
EVENDALE, OHIO

USG AQUIFER
δ^{13} CARBON AND δ^{37} CHLORINE OF 1,1,1-TCA

0 250 500 750 1,000
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

44006\REP\ISO\MXD\007
JUNE 2010

I:\10361\44006\REP\ISO\MXDS\008.MXD

GM-8D
540
GM-5D
GM-9D
PW-01
GM-3D
not detected
AF-22D
AF-15D
AF-16D
AF-1D
27/28-MW-2D
AF-18D
AF-15B
AF-28CMT
OSMW-7D
not detected
AF-17D
PMW-4D
not detected
AF-12D
AF-29CMT
OSMW-4D
not detected
AF-11D
AF-34CMT
PMW-2D
not detected
AF-20D
AF-21D
not detected
AF-19D
AF-5D
not detected
OSMW-12D
not detected
OSMW-12DD
3.6 ug/l
AF-9D
AF-31CMT
AF-32CMT
TMW-1D
not detected
OSMW-9D
not detected
TMW-2D
not detected
AF-33CMT
AF-8D
OSMW-11D
not detected
OSMW-11DD
2.4 ug/l
AF-7D
not detected
OSMW-3D
97 ug/l
δ^{13}C -9.1
δ^{37}Cl 6.19
PMW-3D
130 ug/l
δ^{13}C -22.0
δ^{37}Cl 1.96
MW93
MW92
OSMW-13D
0.6 ug/l
OSMW-13DD
0.7 ug/l
OSMW-6D
not detected
AF-30CMT
OSMW-1D
not detected
δ^{13}C below detection
OSMW-10D
11 ug/l
MW87
MW88
MW89
OSMW-8D
not detected
H-223
535
MW106
MW100
530
PZ-5
PZ-7S
PZ-6
PZ-7D
MW90
MW91
MW105
MW104
H-224
NOTE:
THE MAGNITUDE OF TCE FOR THE SAMPLED WELLS IS DENOTED BY THE SIZE AND COLOR OF THE HIGHLIGHT SURROUNDING THE WELL SYMBOL.
<5 ug/l
>5ug/l and <50 ug/l
>50 ug/l and <500 ug/l
>500 ug/l
OSMW-5D
not detected
H-220
H-218
MW98
MW99
CHAMBERLAIN ST
BYRD AV
MCINTYRE ST
LOCKLAND RD
STEFFENS AV
SIMMONS AV
BEHLES ST
SCHUMARD AV
I-75 EXWY
CATHERINE AV
MILL CREEK EXWY
JONTE AV
HOME AV
WESTVIEW AV
PERSHING AV
HEIMERT AV
SHEPHERD LN
SMALLEY AV
HIGHLANDS AV
FORRER ST
N.COOPER AV
EPPERDING DR
BACON ST
SHEPHERD AV
MC WHORTER ST
MOOCK AV
RIESENBERG LN
BERNARD AV
MCWORTER ST
KOENIG AV
FENTON AV
CARSON ST
JEFFERSON AV
WEST ST
VINE ST
MILL ST
WALNUT ST
BONNELL ST
CAVETT
NORTHBOUND MILL CREEK EXWY
S.COOPER AV
CROSS ST
I-75 EXWY SB
E.FORRER ST
WYOMING AV

PLOT DATE: 02-22-10 jmo

LEGEND

- LSG MONITORING WELLS
- 540.0 — GROUNDWATER CONTOUR (OCTOBER 2009)
- PMW-3D / 130 ug/l / δ^{13}C -22.0 / δ^{37}Cl 1.96 — MONITORING WELL ID; TCE CONCENTRATION (ug/l); δ^{13} CARBON VALUE ($^0/_{00}$ V-PDB); δ^{37} CHLORINE VALUE ($^0/_{00}$ SMOC)
- USG/LSG COMMUNICATION AREA

GE
EVENDALE, OHIO

LSG AQUIFER

δ^{13} CARBON AND δ^{37} CHLORINE OF TCE

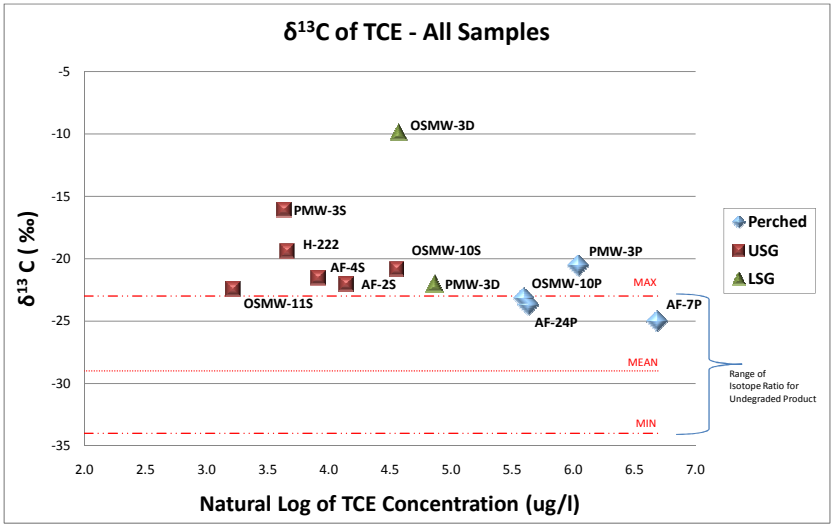
0 250 500 750 1,000
Feet

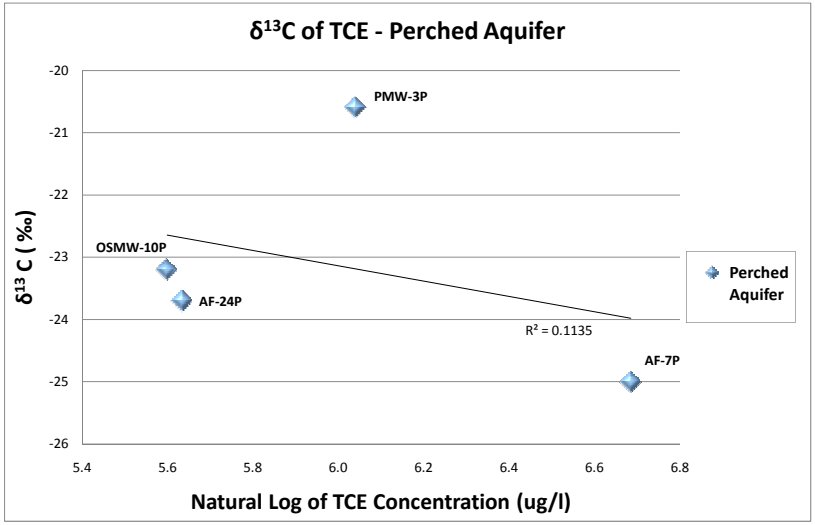
N

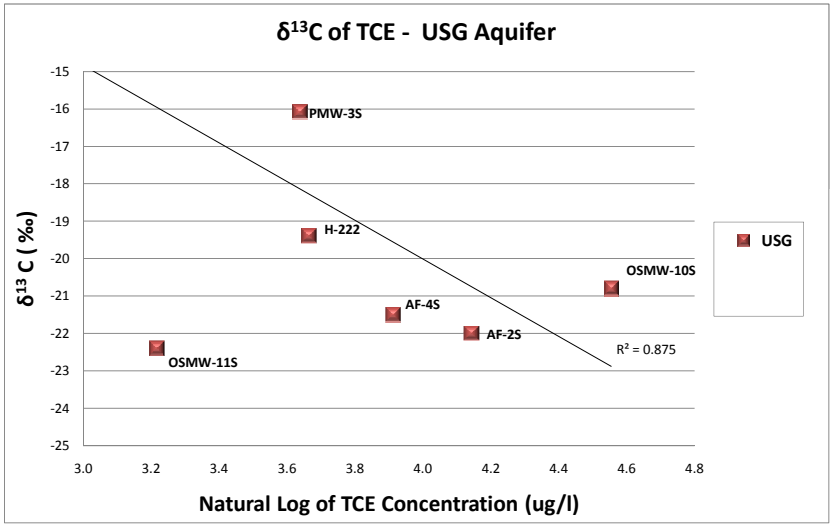
O'BRIEN & GERE ENGINEERS, INC.

10361\44006\REP\ISO\MXD\008
JUNE 2010

Figure 10. Graphs of TCE Concentration versus $\delta^{13}C$







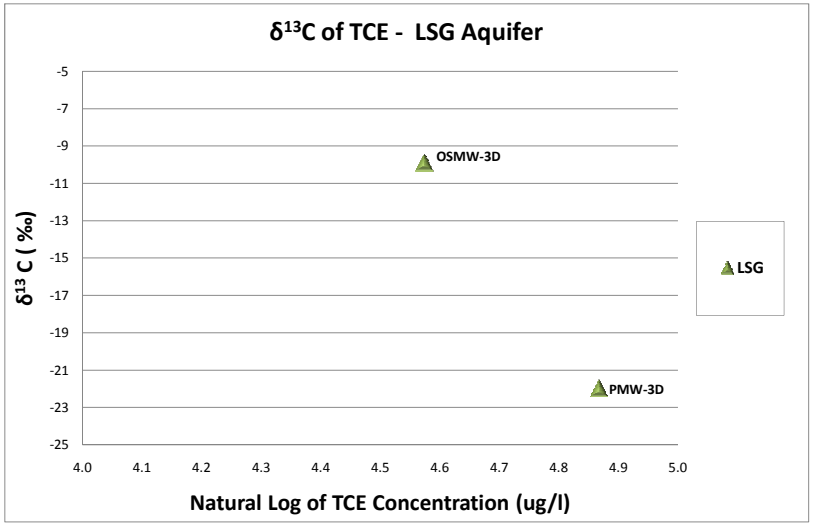
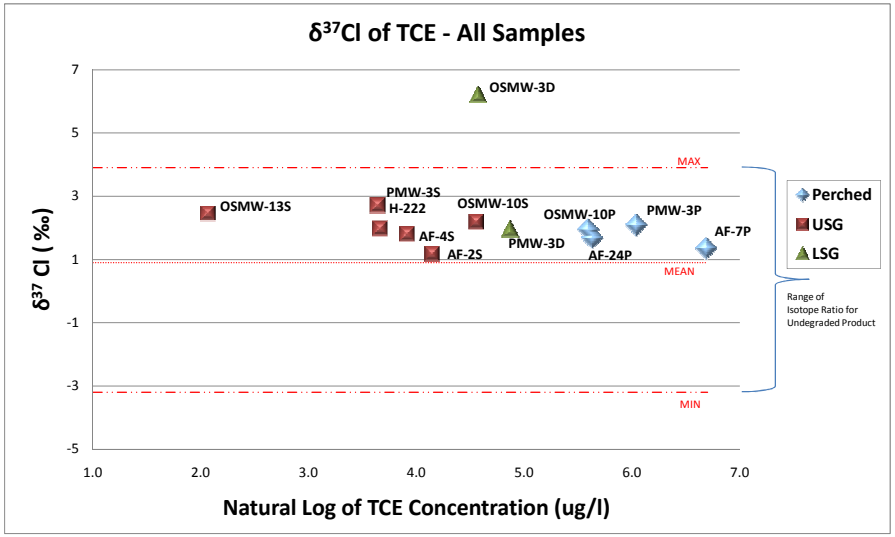
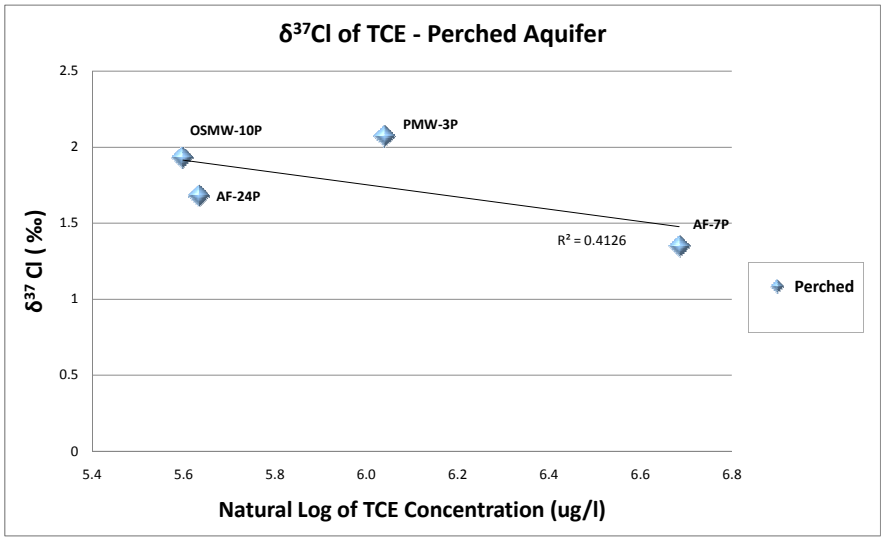
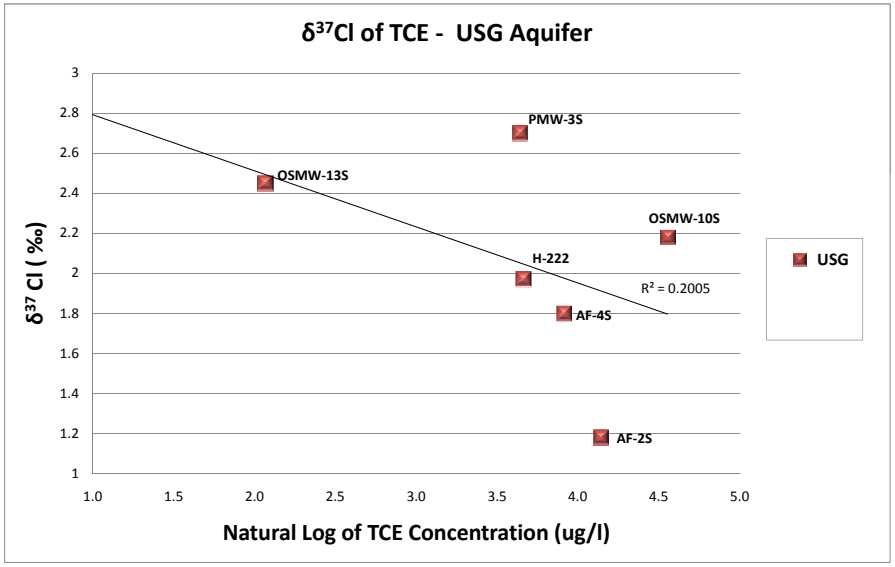


Figure 11. Graphs of TCE Concentration versus $\delta^{37}Cl$







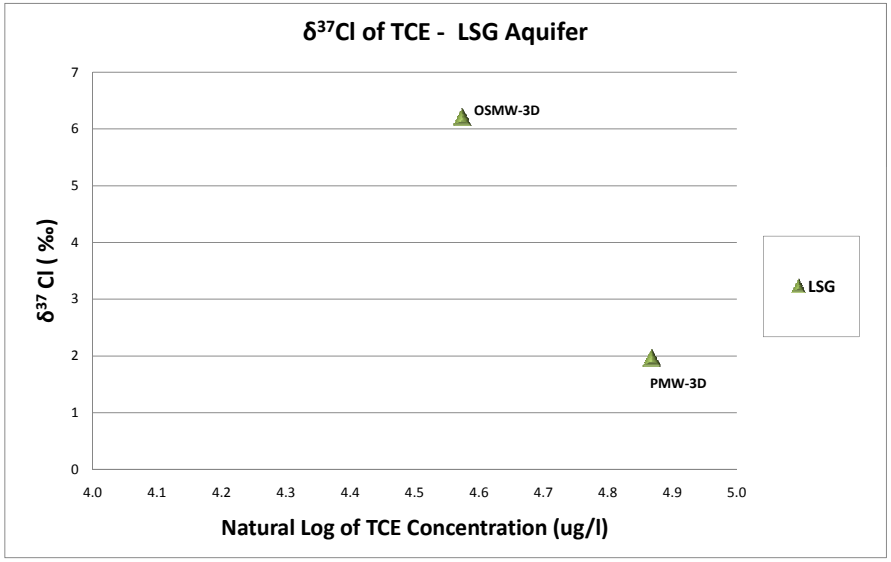
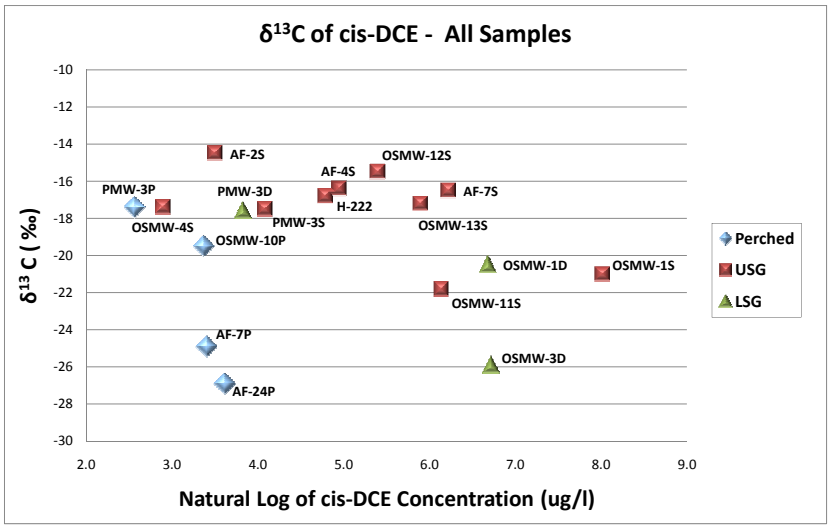
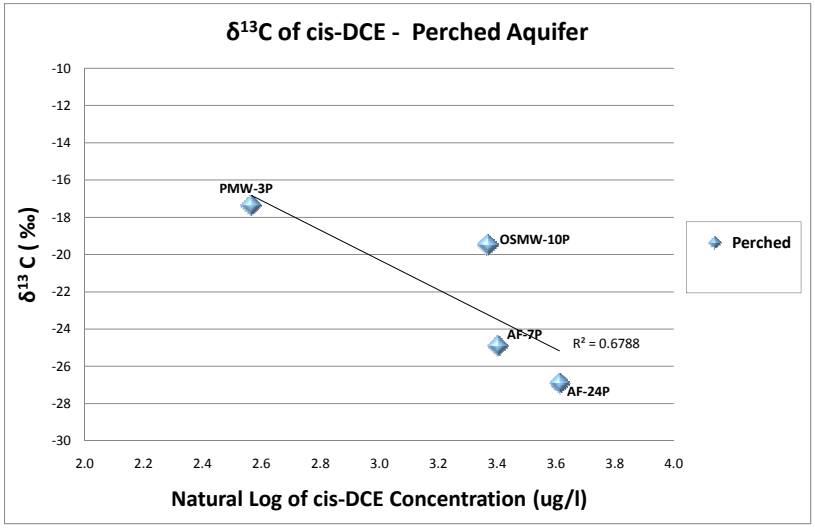
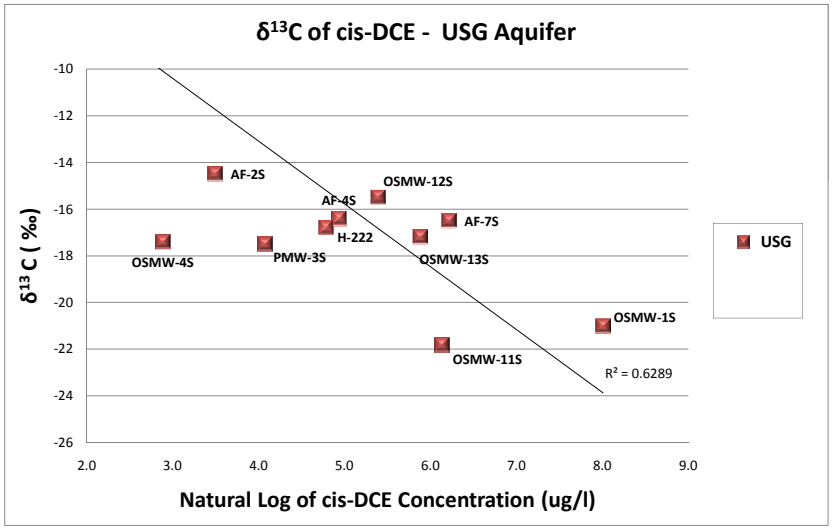


Figure 12. Graphs of Cis-DCE Concentration versus $\delta^{13}C$







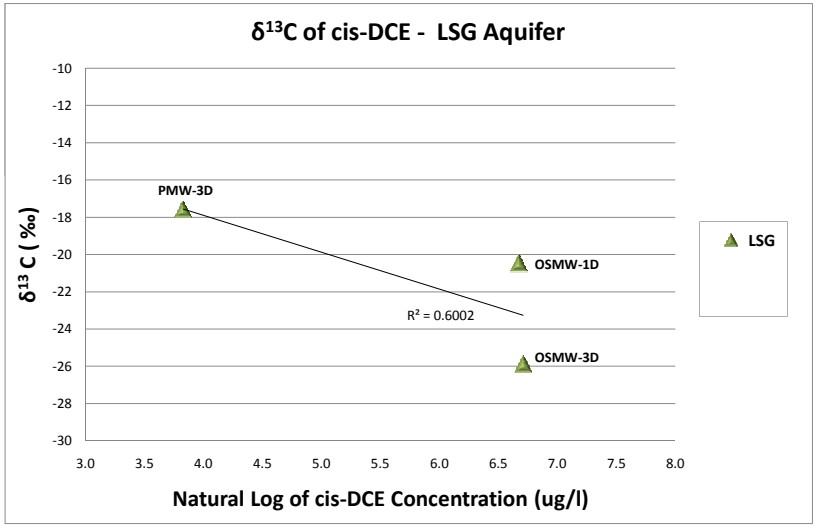
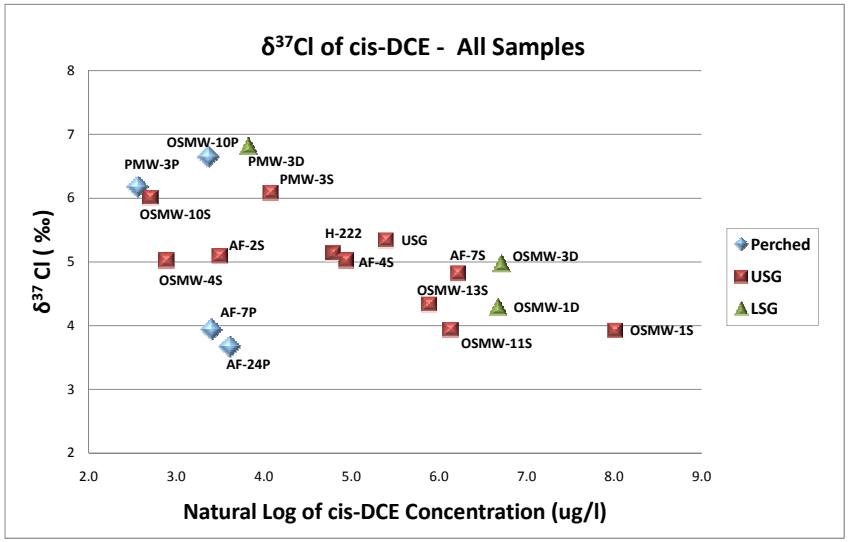
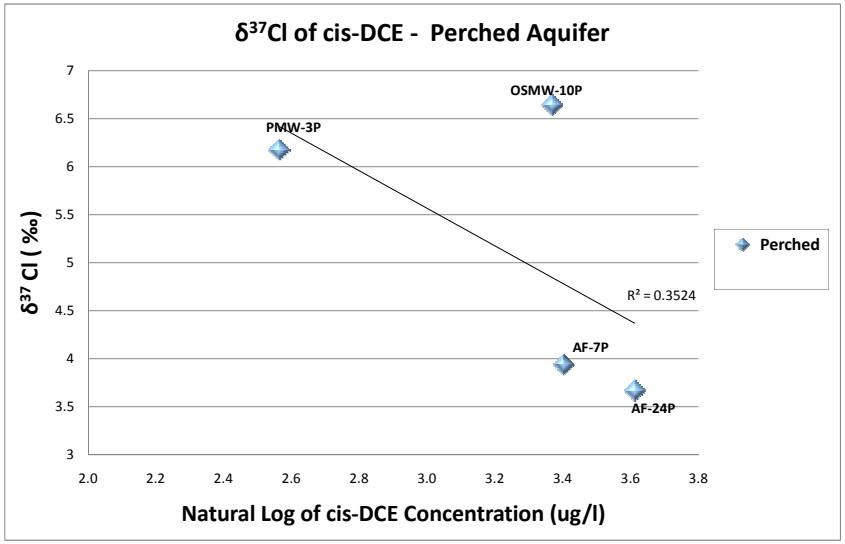
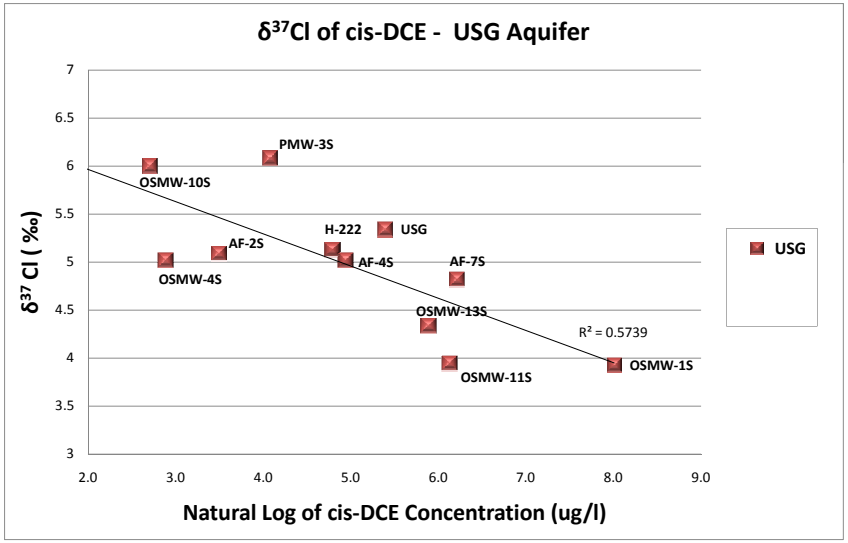


Figure 13. Graphs of Cis-DCE Concentration versus $\delta^{37}Cl$







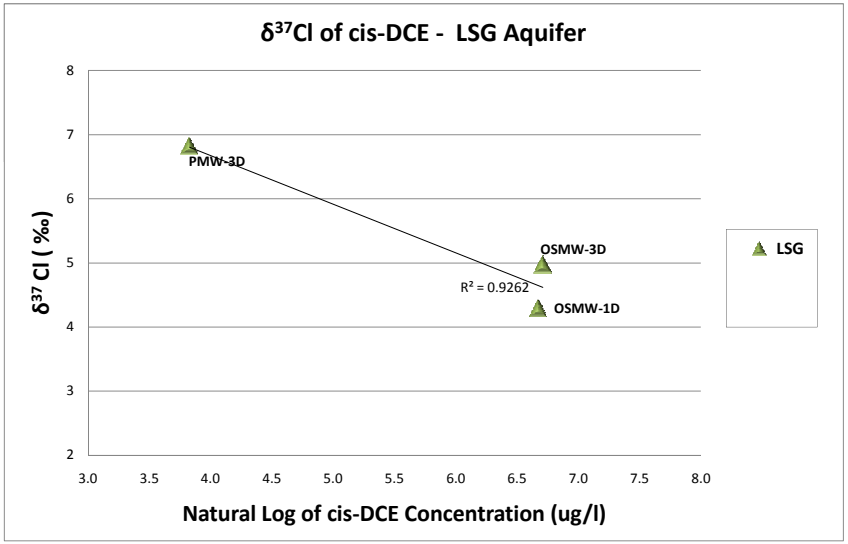
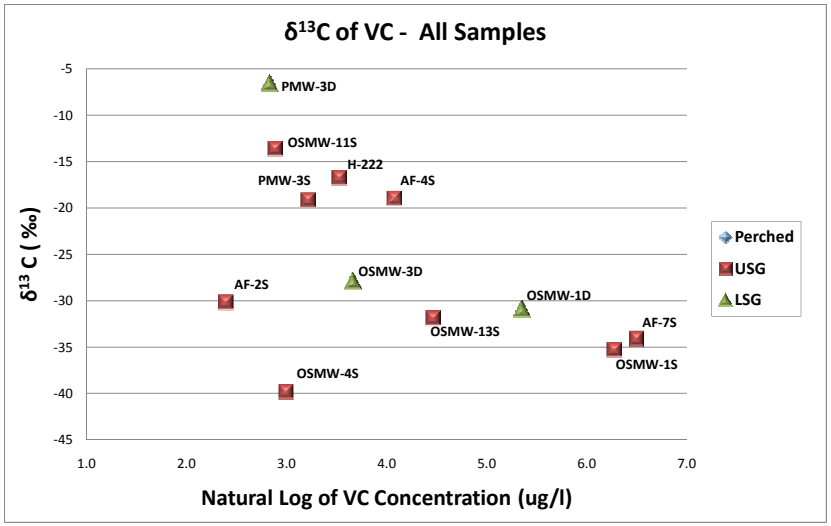
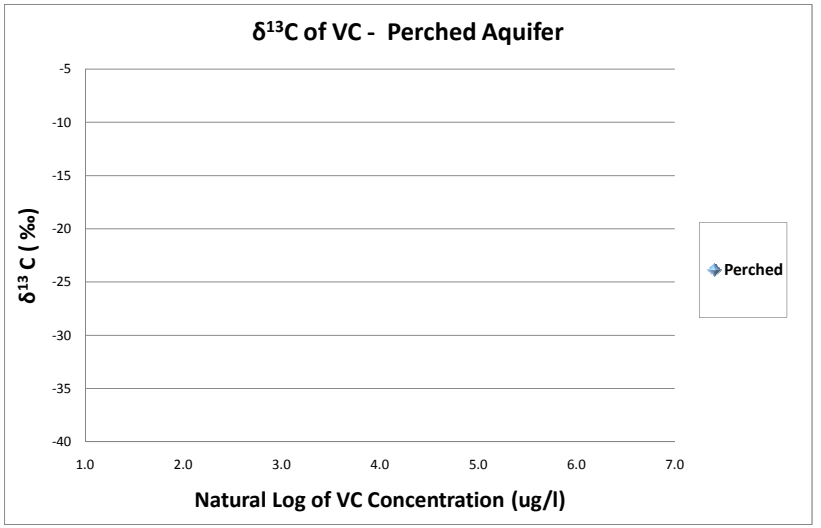
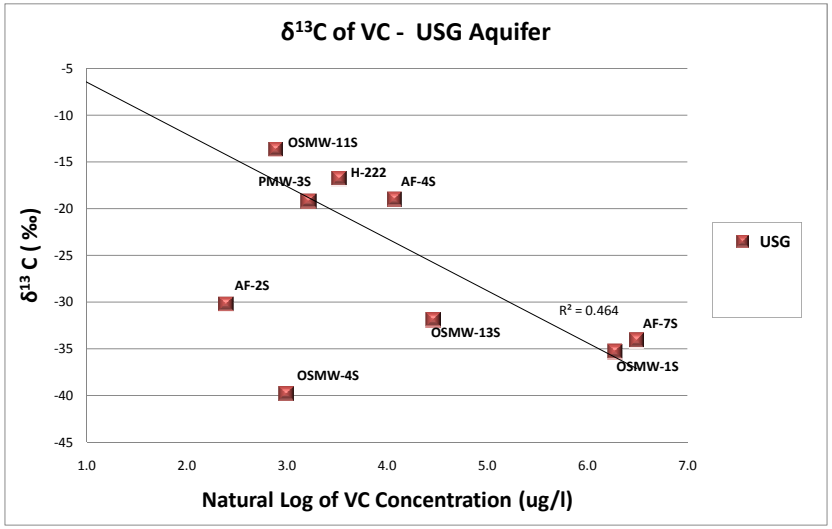


Figure 14 - Graphs of Vinyl Chloride Concentration versus $\delta^{13}C$







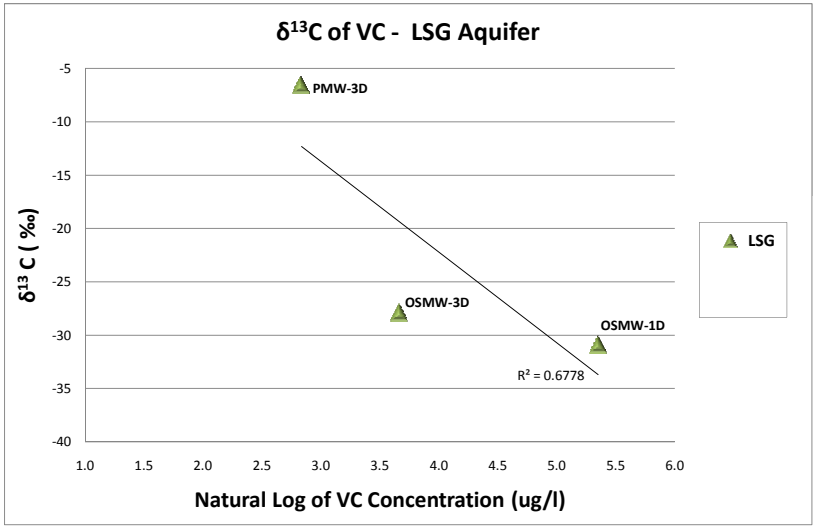
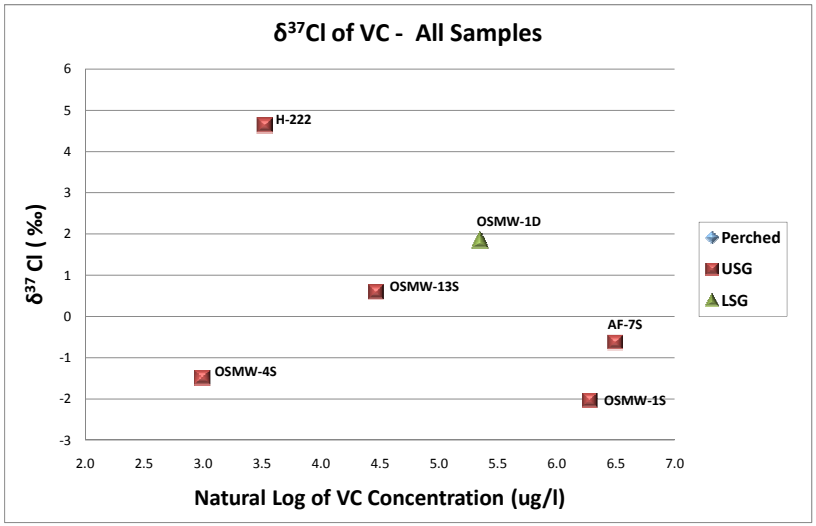
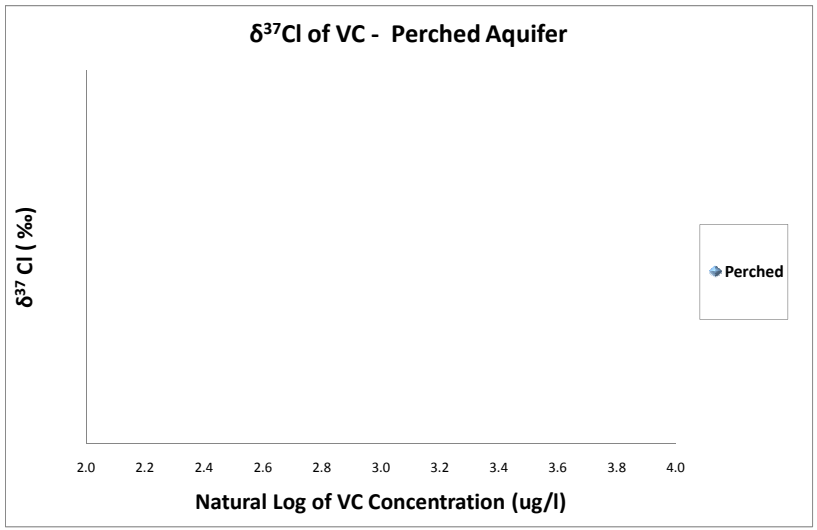
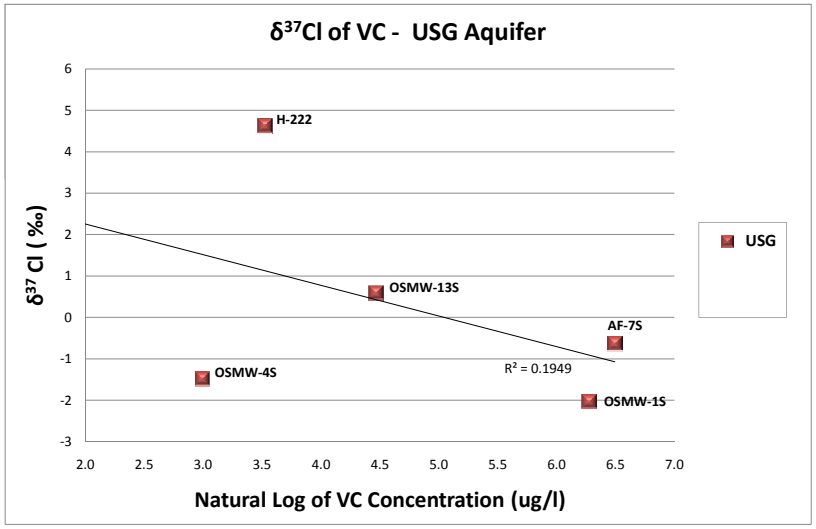


Figure 15. Graphs of Vinyl Chloride Concentration versus $\delta^{37}Cl$







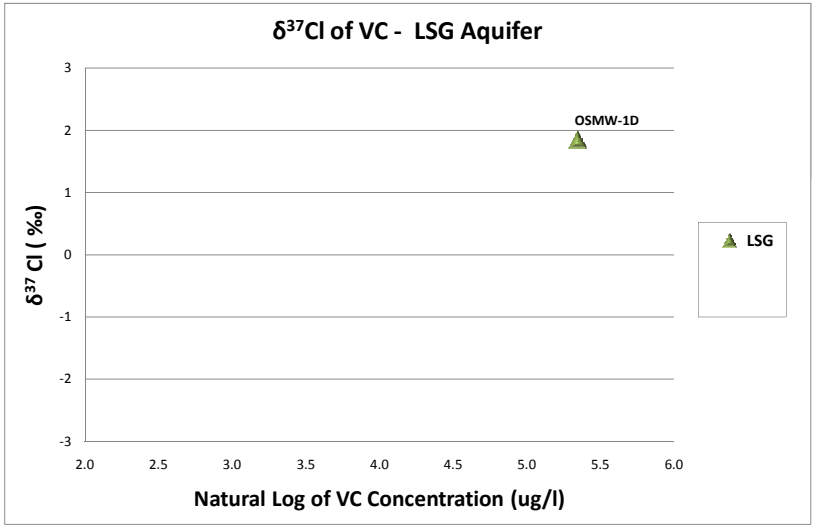
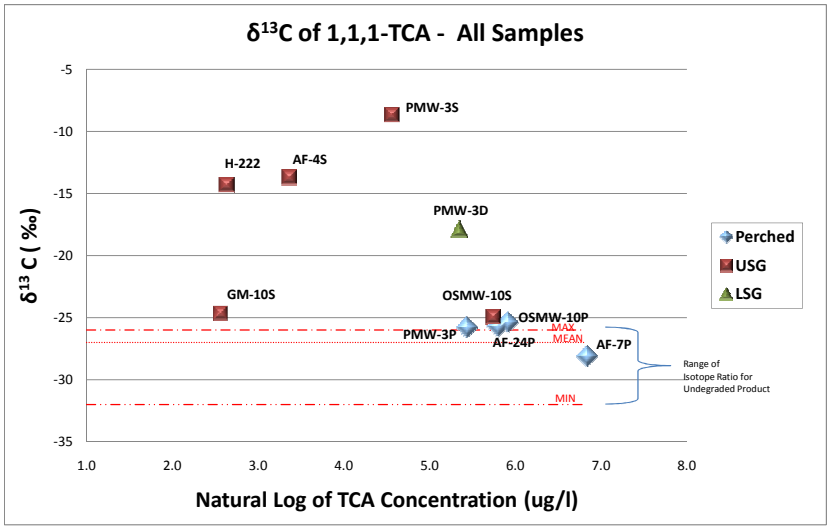
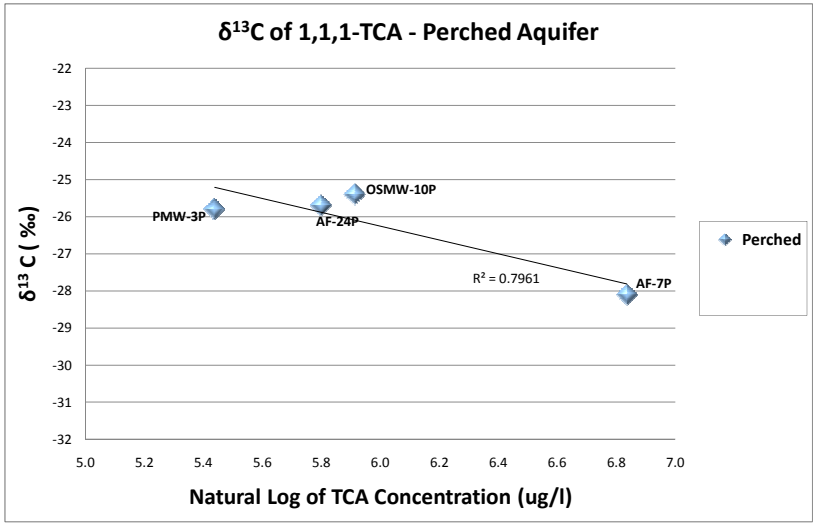
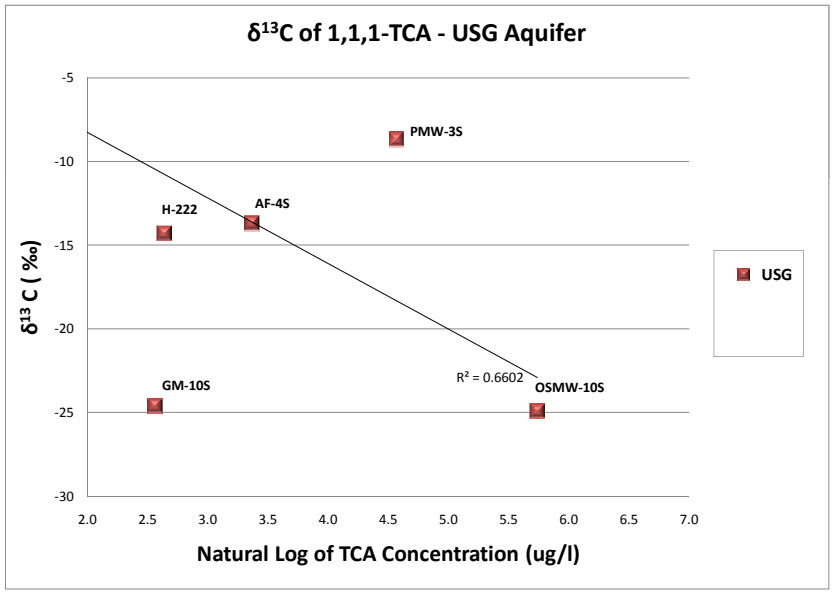


Figure 16. Graphs of 1,1,1-TCA Concentration versus $\delta^{13}C$







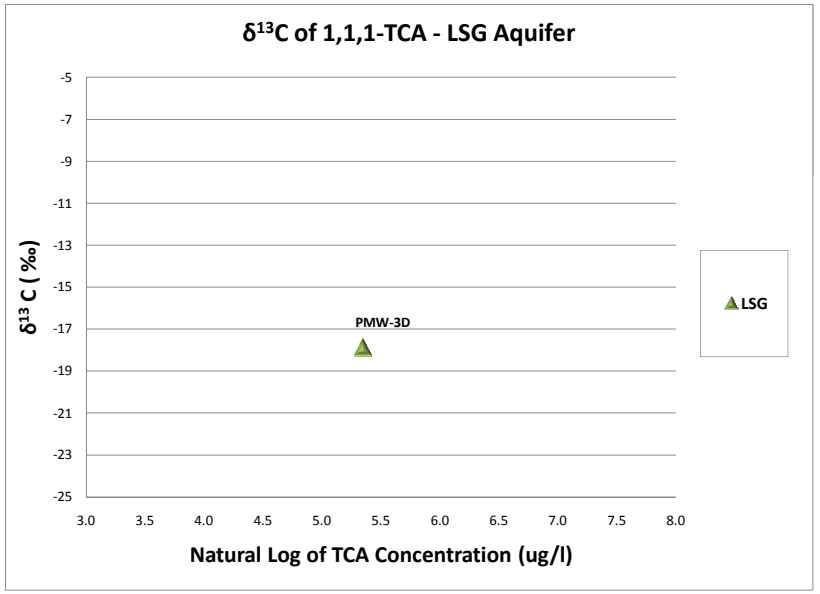
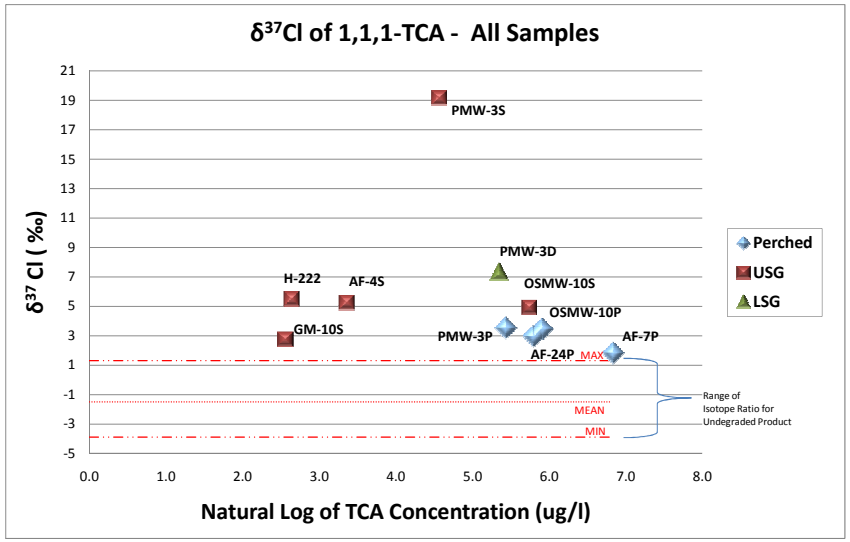
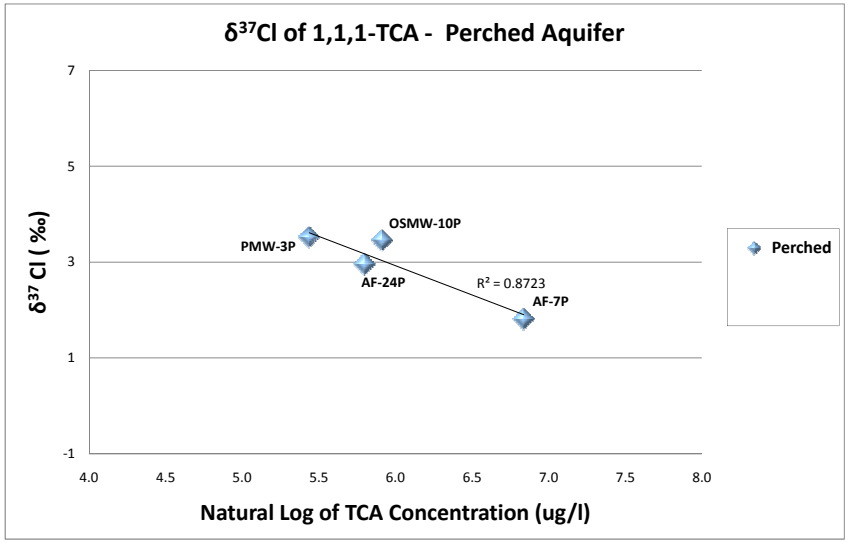
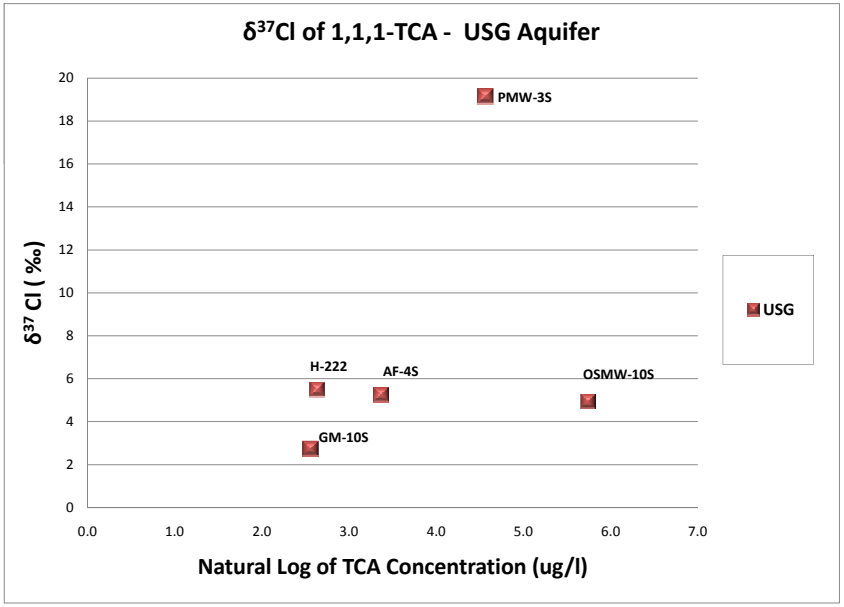


Figure 17. Graphs of 1,1,1-TCA Concentration versus $\delta^{37}Cl$







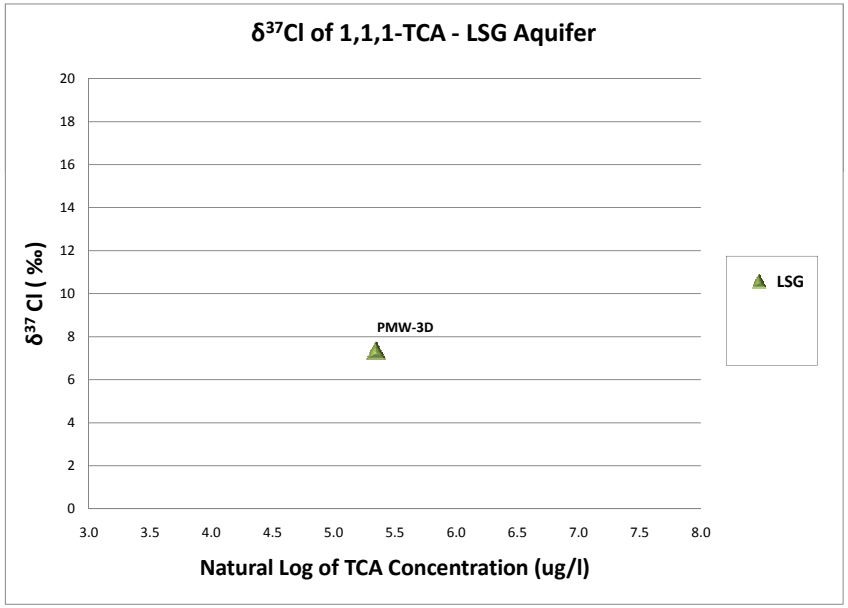
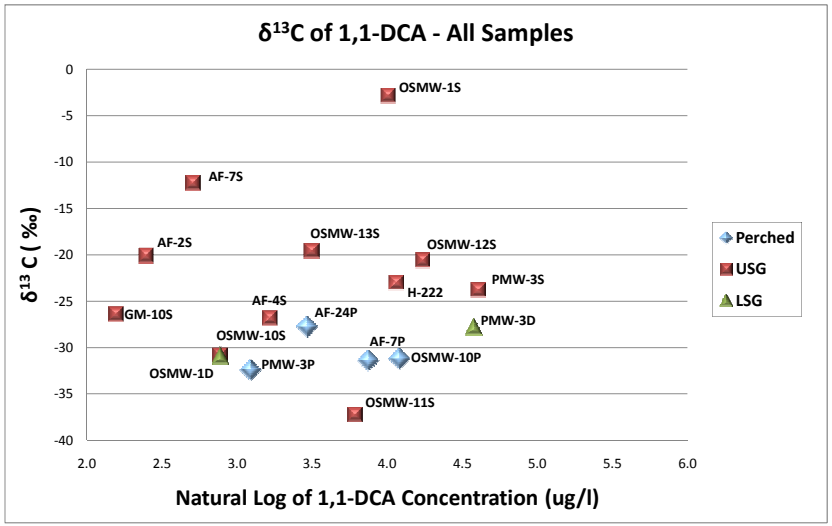
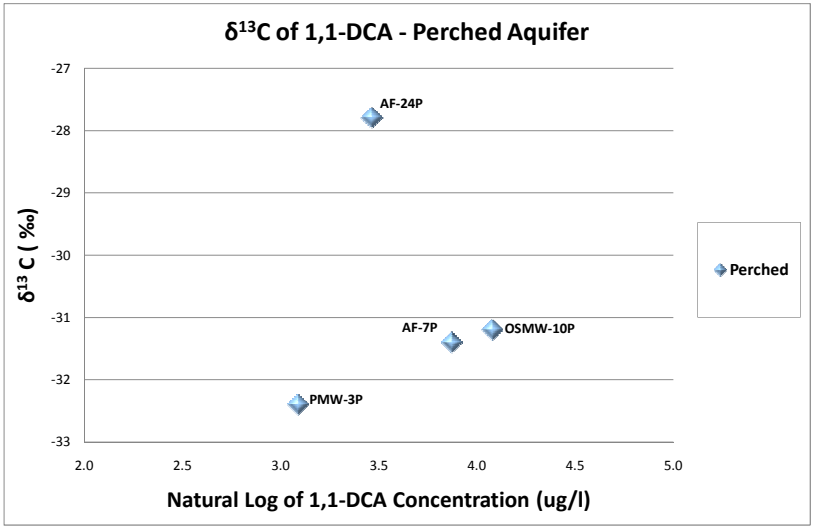
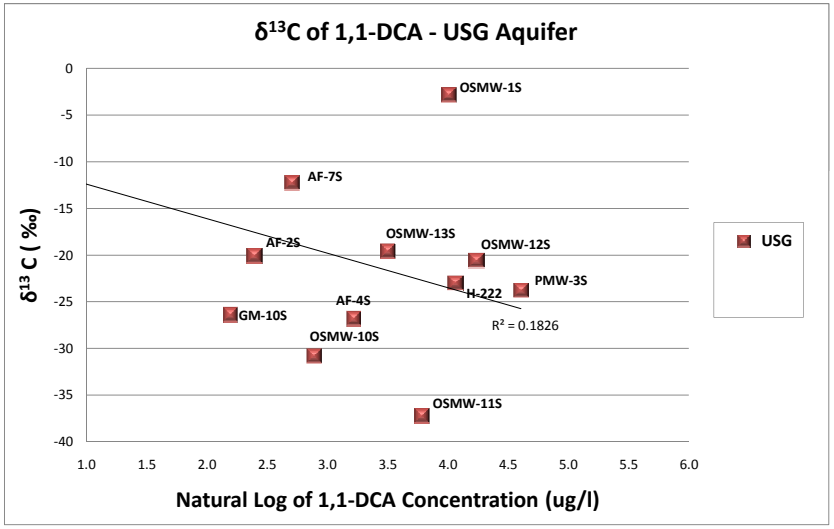


Figure 18. Graphs of 1,1-DCA Concentration versus $\delta^{13}C$







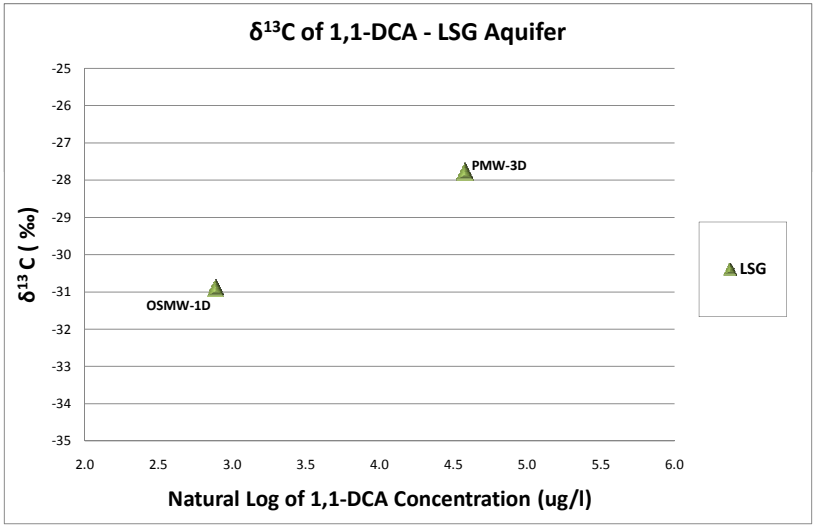
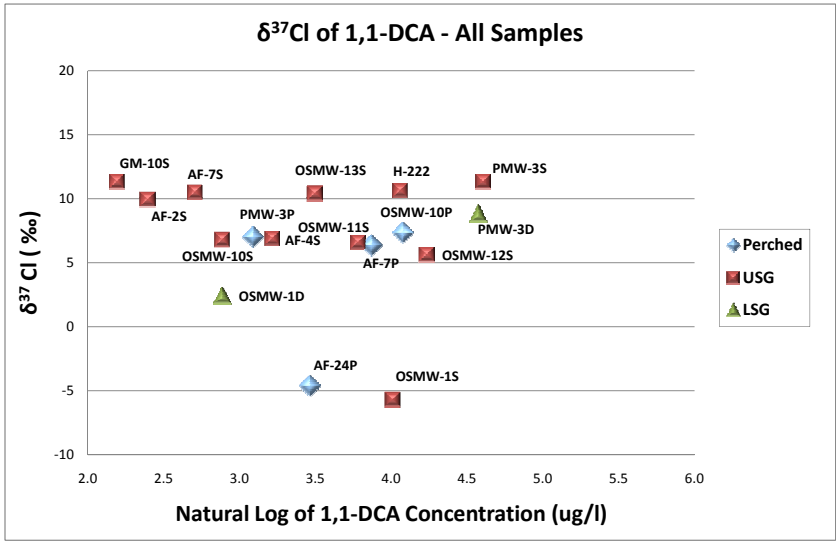
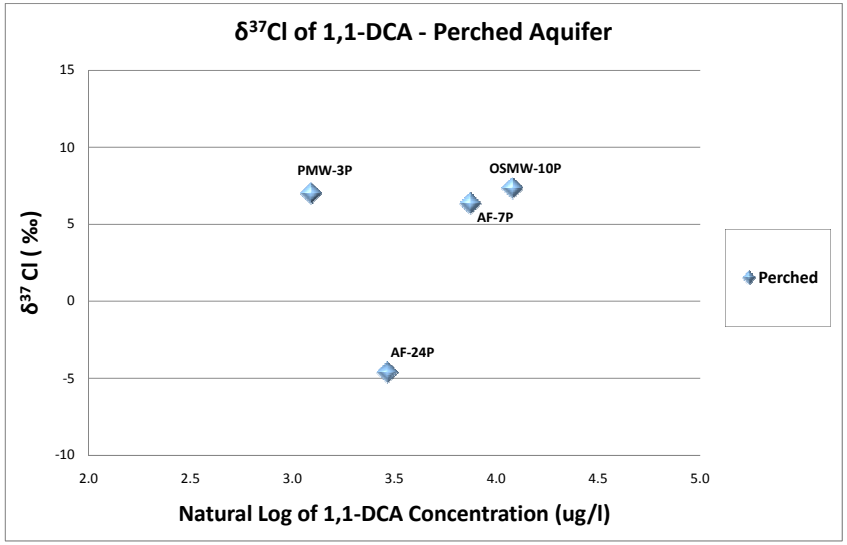
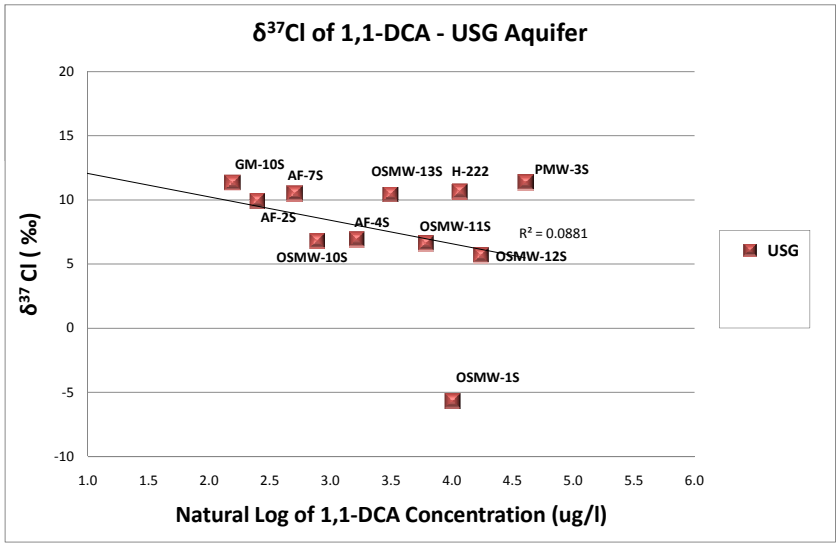


Figure 19. Graphs of 1,1-DCA Concentration versus $\delta^{37}Cl$







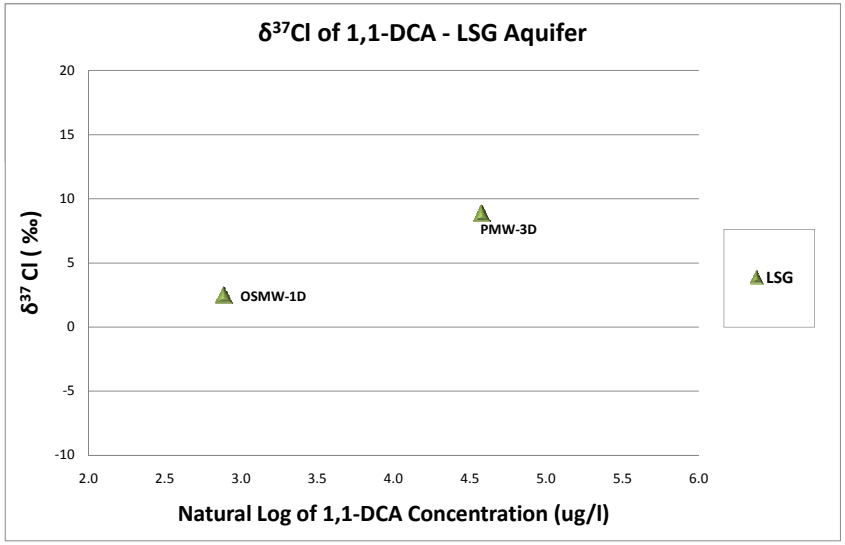
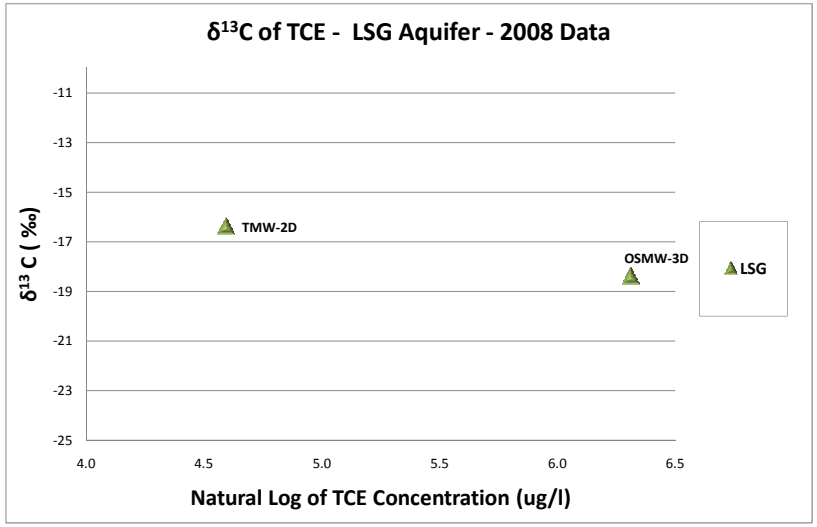
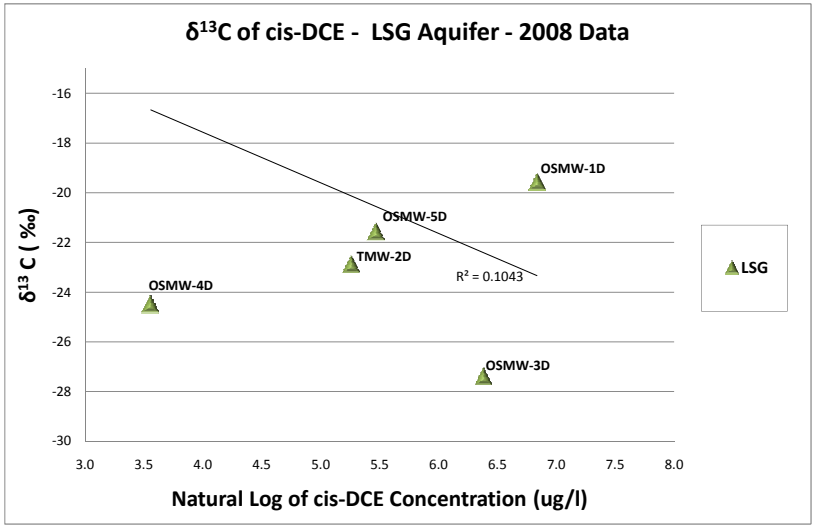
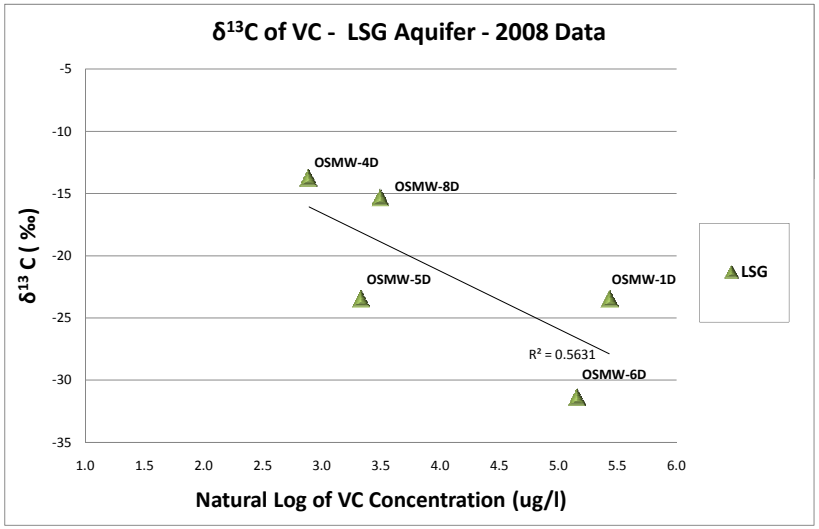


Figure 20. Graphs of TCE - Cis-DCE - Vinyl Chloride Concentration versus $\delta^{13}C$







APPENDICES

Appendix A

Stable Isotope Laboratory Methods and Analytical Results

By Orfan Shouakar-Stash, PhD. (Draft - 20100402)

For O'Brien & Gere [GE Site]

Jun. 6, 2010

Introduction:

In the last 10 years or so, compound specific stable isotope analyses (CSIA) have been increasingly used as an indicator of chemical and biological degradations of chlorinated solvents in groundwater (e.g. Poulson et al., 1997, Hunkeler et al., 1999, Sherwood Lollar et al., 1999, Elsner et al., 2007, Aby et al., 2009) and as a tool to distinguish different plumes (i.e., fingerprinting) and trace them back to the release source point (e.g. Hunkeler et al., 2004; Chartrand et al., 2005; Morrill et al., 2005). CSIA of stable carbon and chlorine isotopes in chlorinated compounds was conducted on groundwater samples to support efforts to evaluate the behaviour of chlorinated ethenes and ethanes at the site.

Methodology:

Compound specific chlorine stable isotope ratios were analyzed at the Environmental Isotope Laboratory (EIL), at the University of Waterloo, Canada by the means of a continuous flow-isotope ratio mass spectrometer (CF-IRMS) (Isoprime, Micromass, UK) equipped with an Agilent 6890 gas chromatograph (GC) and a CTC analytics CombiPAL autosampler as described by Shouakar-Stash et al., 2006 and 2009.

Briefly, samples were prepared and analyzed as follows:

1. Each organic compound was analyzed separately (i.e. samples were analyzed for TCE then cis-DCE and so on).
2. All samples were prepared for each analysis in 20 ml vials and samples were diluted if necessary to achieve similar concentrations for all samples.
3. The chlorinated solvents were extracted by the means of solid phase micro extraction (SPME).

4. The chlorinated solvents were then injected on a GC capillary column (DB-624 GC (30 m, 0.320 mm, 1.80 μm film) for VC and DB-5 MS GC (60 m, 0.320 mm, 1 μm film) for all other VOCs analyzed during this study) to facilitate the separation of the various organic compounds.
5. The desired organic compound was directed to IRMS to be analyzed for compound specific chlorine stable isotope values and the remaining compounds were directed to the waste.
6. Samples were bracketed by in-house standards that are calibrated to standard Mean Ocean Chloride (SMOC). The $^{37}Cl/^{35}Cl$ ratios were reported in the delta notation ($\delta^{37}Cl$) referenced to SMOC (Standard Mean Ocean Chloride) standard. The delta notation is defined as $\delta = (R_{sample}/R_{reference} - 1) \times 1000$, where R_{sample} and $R_{reference}$ are the chlorine isotope ratios of the aqueous sample and the respective standards.
7. In general, each ten samples are bracketed by 12 standards before and 12 standards after.
8. Generally, most samples were analyzed at least two times and average and a standard deviation was calculated and reported.
9. The standards that were used were prepared with different concentration to correct for any linearity issue if there is any.
10. All isotopic values of the samples were corrected relative to the standards and reported relative to SMOC, except for 1,1-DCA that was reported relative to 1,1-DCA-A.
11. The precision for chlorine isotope analysis is usually ± 0.1 ‰ for TCE and cis-DCE, ± 0.16 ‰ for VC and usually better than ± 0.20 ‰ for 1,1-DCA and 1,1,1-TCA.

Compound specific carbon stable isotope analyses were performed on a Finnigan Delta XP (CF-IRMS) at the Stable Isotope Laboratory, the University of Toronto, Canada. The analytical procedure is described below:

1. The VOC were collected through a TELEDYNE-TEKMAR Velocity XPT purge and trap unit, equiped with home-made 60 ml vessels and a trap K.
2. The purge and trap program is as follow: 20 minutes purge with 40 ml Helium per min, sample vessel, trap and moisture trap at 30°C, 2 min dry purge with 40 ml He sample

vessel and trap at 30°C, moisture trap at 120°C. Trap desorbed for 4 min at a flow of 10 ml/min at 250°C. Then, Baked for 10 min at 260°C with a 100 ml/min He flow.

3. VOC then, were separated by the means of an Agilent 9850 GC (60 m long, 0.32 mm ID, 1.5 nm phase thickness VOCOL column). GC program 35°C hold 3min, ramp to 110°C at 4°C/min, then ramp to 220°C at 10°C/min then hold 15 min.
4. After the separation, the organic compounds were oxidized through a capillary oven (35 cm long, 0.5 mm ID) that was maintained at 950°C. The Oxidation tube contained 2 CuO, 1 NiO and 1 Pt wires.
5. Every sample were run in duplicate using 40 ml (one vial), the two values are averaged to be send to clients.
6. Mixtures of VOC of known Carbon isotope ratio (standards), diluted to the same composition than the sample, were run before, after and in the middle of the analytical runs.
7. All of the $\delta^{13}C$ values of the various VOCs were reported relative to Vienna Pee Dee Belemnite (VDPB).
8. Even if the reproducibility on standards and samples were lower than 0.5 ‰, the results are presented (taking into account accuracy and reproducibility) with an error of ± 0.5 ‰.

Results:

The $\delta^{37}Cl$ and $\delta^{13}C$ values of five chlorinated compounds (TCE, cis-DCE, 1,1,1-TCA, 1,2-DCA and VC) of several samples from three different aquifers (Perched, USG and LSG aquifers) were determined and the results are presented in Table-1 and Table-2, respectively. All $\delta^{37}Cl$ values were reported relative to SMOC except for the 1,1-DCA results that were reported relative to 11DCA-A an in-house standard of EIL. The $\delta^{13}C$ results were reported relative to Vienna Pee Dee Belemnite (VPDB).

Table-1: The $\delta^{37}Cl$ (‰) values of TCE, 1,1-DCA, 1,1,1-TCA, cis-DCE and VC of the GE site samples.

Sample ID	δ37Cl (TCE) ‰		δ37Cl (1,1-DCA) ‰		δ37Cl (1,1,1-TCA) ‰		δ37Cl (cis-DCE) ‰		δ37Cl (VC) ‰	
	Result	Stdv	Result	Stdv	Result	Stdv	Result	Stdv	Result	Stdv
	SMOC		11DCA-A		SMOC		SMOC		SMOC	
OSMW-10P/30/111209	1.93	0.18	7.32	0.13	3.44	0.07	6.64	0.11		
OSMW-12S/50/111209			5.63	0.28			5.34	0.11		
OSMW-10S/57/111209	2.18	0.1	6.77	0.19	4.95	0.04	6	0.11		
OSMW-3D/143/111209	6.19	0.08					4.97	0.04		
OSMW-11S/47/111209			6.58	0.13			3.95	0.08		
H-222/48/111209	1.97	0.04	10.59	0.08	5.51	0.23	5.13	0.11	4.62	0.06
OSMW-4S/75/111209							5.02	0.11	-1.48	0.24
OSMW-13S/48/111209	2.45	0.05	10.37	0.19			4.34	0.12	0.59	0.14
OSMW-1D/92/111209			2.44	0.34			4.29	0.08	1.84	0.15
AF-7P/36/111209	1.35	0.1	6.33	0.09	1.82	0.04	3.94	0.16		
AF-7S/55/111209			10.46	0.21			4.82	0.06	-0.63	0.13
PMW-3P/26/111209	2.07	0.12	6.98	0.21	3.51	0.05	6.17	0.08		
PMW-3S/54/111209	2.7	0.09	11.29	0.1	19.13	0.23	6.08	0.08		
PMW-3D/136/111209	1.96	0.1	8.78	0.19	7.34	0.09	6.81	0.28		
OSMW-1S/53/111209			-5.67	0.33			3.93	0.05	-2.03	0.4
GM7S/53/111209										
AF-3S/52/111209										
GM1/55/111209										
GM-10S/40/111209			11.28	0.06	2.77	0.11				
AF-4S/53/111209	1.8	0.09	6.88	0.11	5.27	0.18	5.02	0.08		
GM-11S/57/111209										
GM-3S/54/111209										
AF-24P/36/111209	1.68	0.17	-4.61	0.25	2.95	0.17	3.67	0.06		
AF-2S/49/111209	1.18	0.14	9.88	0.16			5.09	0.13		

Table-2: Concentration (µg/L) results and $\delta^{13}C$ (‰) values of TCE, 1,1-DCA, 1,1,1-TCA, cis-DCE and VC of the GE site samples.

Sample ID	TCE		1,1-DCA		1,1,1-TCA		cis-DCE		VC	
	Conc. (µg/L)	δ13C (‰) VPDB	Conc. (µg/L)	δ13C (‰) VPDB	Conc. (µg/L)	δ13C (‰) VPDB	Conc. (µg/L)	δ13C (‰) VPDB	Conc. (µg/L)	δ13C (‰) VPDB
OSMW-10P/30/111209	270	-23.2	59	-31.2	370	-25.4	29	-19.5	5	B.D.
OSMW-12S/50/111209	0	B.D.	69	-20.6	0	B.D.	220	-15.5	13	B.D.
OSMW-10S/57/111209	95	-20.8	18	-30.8	310	-24.9	15	B.D.	9	B.D.
OSMW-3D/143/111209	97	-9.92	6	B.D.	0	B.D.	820	-25.9	39	-27.9
OSMW-11S/47/111209	25	-22.4	44	-37.2	ND	B.D.	460	-21.8	18	-13.7
H-222/48/111209	39	-19.4	58	-23	14	-14.3	120	-16.8	34	-16.8
OSMW-4S/75/111209	0	B.D.	0	B.D.	0	B.D.	18	-17.4	20	-39.8
OSMW-13S/48/111209	7.9	B.D.	33	-19.6	ND	B.D.	360	-17.2	87	-31.9
OSMW-1D/92/111209	0	B.D.	18	-30.9	0	B.D.	790	-20.5	210	-30.9
AF-7P/36/111209	800	-25	48	-31.4	930	-28.1	30	-24.9	ND	B.D.
AF-7S/55/111209	ND	B.D.	15	-12.3	ND	B.D.	500	-16.5	660	-34.1
PMW-3P/26/111209	420	-20.6	22	-32.4	230	-25.8	13	-17.4	0	B.D.
PMW-3S/54/111209	38	-16.1	100	-23.8	96	-8.7	59	-17.5	25	-19.2
PMW-3D/136/111209	130	-22	97	-27.8	210	-17.9	46	-17.6	17	-6.6
OSMW-1S/53/111209	ND	B.D.	55	-2.9	ND	B.D.	3000	-21	530	-35.3
GM7S/53/111209										
AF-3S/52/111209										
GM1/55/111209										
GM-10S/40/111209	0	B.D.	9	-26.4	13	-24.6	0	B.D.	0	B.D.
AF-4S/53/111209	50	-21.5	25	-26.8	29	-13.7	140	-16.4	59	-19
GM-11S/57/111209										
GM-3S/54/111209										
AF-24P/36/111209	280	-23.7	32	-27.8	330	-25.7	37	-26.9		-34.2
AF-2S/49/111209	63	-22	11	-20.1	6	B.D.	33	-14.5	11	-30.2

ND: Not detected

B.D.: Below detection limit.

References:

Abe, Y., Aravena, R., Zopfi, J., Shouakar-Stash, O., Roberts, J.D. and Hunkeler, D. (2009) Carbon and chlorine isotope fractionation during aerobic oxidation and reductive dechlorination of vinyl chloride and cis-1,2-dichloroethene. Environmental Science and Technology. Environmental Science and Technology. vol. 43, 101-107.

Chartrand, M.G., Waller, A., Mattes, T. E., Elsner, M., Lacrampe-Couloume, G., Gossett, J. M., Edwards, E., and Sherwood Lollar, B. (2005) Carbon Isotopic Fractionation during Aerobic Vinyl Chloride Degradation. Environ. Sci. Technol., vol. 39, 1064-1070.

Elsner, M., Cwiertny, D.M., Roberts, A.L. and Sherwood-Lollar, B. (2007) 1,1,2,2-tetrachloroethane reactions with OH-, Cr(II), granular iron and a copper-iron bimetal: Insights from product formation and associated carbon isotope fractionation, Environ. Sci. Technol., vol. 41, 4111-4117.

Hunkeler, D., Aravena, R. and Butler, B.J. (1999) Monitoring microbial dechlorination of tetrachloroethene (PCE) in groundwater using compound-specific stable carbon isotope ratios: Microcosm and field studies. Environ. Sci. Technol., vol. 33, 2733-2738.

Hunkeler, D., Chollet, N., Pittet, X., Aravena, R., Cherry, J.A. and Parker, B.L. (2004) Effect of source variability and transport processes on carbon isotope ratios of TCE and PCE in two sandy aquifers. Journal of Contaminant Hydrology, vol. 74, 265- 282.

Morrill, P., Lacrampe-Couloume, G., Slater, G.F., Sleep, B.E., Edwards, E.A., McMaster, M.L., Major, D.W., and and Sherwood Lollar, B. (2005) Quantifying chlorinated ethene degradation during reductive dechlorination at Kelly AFB using stable carbon isotopes. Journal of Contaminant Hydrology. vol. 76, 279-293.

Poulson, S.R., Drever, J.I., Colberg, P.J.S., (1997) Estimation of KOC values for deuterated benzene, toluene, and ethylbenzene and application to groundwater contamination studies. Chemosphere. vol. 35, 2215-2224.

Sherwood Lollar, B., Slater, G.F., Ahada, J., Sleep, B., Spivack, J., Brennan, M., and MacKenzie, P. (1999) Contrasting carbon isotope fractionation during biodegradation of trichloroethylene and toluene: Implications for intrinsic bioremediation. Organic Geochemistry. vol. 30, 813-820.

Shouakar-Stash, O., Drimmie, R.J., Zhang, M., and Frape, S.K. (2006) Compound-specific chlorine isotopes ratio of TCE, PCE and DCE isomers by direct injection using CF-IRM. Applied Geochemistry, vol. 21, 766-781.

Shouakar-Stash, O., Frape, S.K., Gargini, A., Pasini, M., Drimmie, R.J. and Aravena, R., (2009) Analysis of Compound-Specific Chlorine Stable Isotopes of Vinyl Chloride by Continuous Flow-Isotope Ratio Mass Spectrometry (CF-IRMS). Environmental Forensics Journal. Vol. 10, 299-306.

Appendix B

Data Validation Summary Report – November 2009 Performance Monitoring Event

From: Karen Storne
Re: GE Aviation, IRM Off-Site Investigation IRM Performance Monitoring Data Validation Report
File: 10361/44006.001.001
Date: January 11, 2010

cc: M. Kleiman
T. Finch
C. Yantz

Data validation was performed on analytical results for samples collected November 2009 as part of the General Electric (GE) Aviation Off-Site Investigation IRM Performance Monitoring and at the Evendale, Ohio facility.

Samples were analyzed by TestAmerica Buffalo of Amherst, New York (TA Buffalo). The laboratory utilized United States Environmental Protection Agency (USEPA) methods for sample analysis and the data packages contained summary forms for quality control analysis and supportive raw data.

The following table summarizes the analyses submitted for data validation.

Table 1. *Analytical methods and references*

Parameter	Method	Reference
VOCs	USEPA Methods 5030B/8260B	1

Note:
1. United States Environmental Protection Agency (USEPA). 2004. *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, SW-846,* 3rd Edition, Update IIIB. Washington D.C.

VOCs indicates volatile organic compounds

The samples submitted for data validation are summarized in attached Table 2. Table 3 presents the specific data validation approach applied to data generated for this investigation. Table 4 presents the Laboratory QA/QC analyses definitions.

Full validation was performed on the aqueous samples collected for this investigation using the quality assurance/quality control (QA/QC) criteria established in the USEPA Methods and the USEPA approved SAP.

Data affected by excursions from criteria presented in the USEPA Methods were qualified using professional judgment and guidance provided in the following documents:

- O'Brien & Gere. 2009. *Sampling and Analysis Plan (SAP), General Electric Company, Evendale, Ohio.* Farmington Hills, Michigan.
- USEPA. 1999. *USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review, EPA-540/R-99-008.* Washington D.C.

The USEPA data validation guidelines have been modified to reflect the requirements of the method and the SAP used in the analysis of these samples. Qualifiers were applied to data that failed to meet the quality control criteria presented in the USEPA methods and the SAP.

The data validation included evaluating the following parameters:

- SAP compliance
- Chain-of-custody records, shipment, and sample collection
- Holding times and sample preservation
- Calibrations
- Blank analysis
- Matrix spike/matrix spike duplicate (MS/MSD) analysis
- Laboratory control sample (LCS) analysis

- Field duplicate analysis
- Surrogate recoveries
- Internal standards performance
- Gas chromatography/mass spectrometry (GC/MS) instrument check
- Target analyte quantification, identification, and quantitation limits (QLs)
- Documentation completeness

The following sections of this memorandum present the results of the comparison of the analytical data to the QA/QC criteria specified in USEPA Methods, the validation criteria applied to this analysis, and the qualifiers assigned to the data when the QA/QC criteria were not met. Additional observations are presented in the following sections.

SAP COMPLIANCE

As directed by the Project Manager, the target analyte list provided in the QAPP has been revised; the following target analytes were removed from the QAPP list for VOCs: 1,1,2-trichloro-1,2,2-trifluoroethane, 1,2,4-trichlorobenzene, 1,2-dibromo-3-chloropropane, 1,2-dibromoethane, 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, 1,4-dioxane, cyclohexane, dichlorodifluoromethane, isopropylbenzene, methyl acetate, methyl tert-butyl ether, methylcyclohexane, trichlorofluoromethane.

DOCUMENTATION COMPLETENESS

Supplemental documentation was required during the validation process to complete the validation task.

CHAIN-OF-CUSTODY RECORDS, SHIPMENT AND SAMPLE COLLECTION

A trip blank was not provided with the samples collected 11/11/09. The impact of this sample collection issue is addressed in the following section. The Project Manager was informed of this issue.

VOC DATA EVALUATION SUMMARY

Excursions from quality control criteria and additional observations are summarized below.

I. Holding times and sample preservation

The method and validation analysis holding time criterion of 14 days from collection for preserved aqueous samples for VOCs was met.

II. Blank analysis

Trip blanks, equipment blanks, and method blanks were analyzed to evaluate blank excursions.

A trip blank was not provided with the samples collected 11/11/09. Therefore, the potential contamination of samples due to sample shipment could not be evaluated for the samples collected 11/11/09.

The following results were qualified as non-detected (U) due to minor blank excursions:

- Results for acetone in samples OSMW-12P 110609, OSMW-12S 110609, OSMW-12D 110609, OSMW-12DD 110609, OSMW-11P 110609, OSMW-11S 110609, OSMW-11D 110609, OSMW-11DD 110609, OSMW-13P 110609, OSMW-13S 110609, OSMW-13DD 110609, OSMW-10S 111009, OSMW-10P 111009, OSMW-10D 111009, PMW-3P 111009, PMW-3S 111009, PMW-3D 111009, TMW-2P 111009, PMW-2D 111009, PMW-4D 111009, ADW-4D 111009 [PMW-4D 111009], GM-9S 111009, GM-3D 111009, ADW-3D 111009 [GM-3D 111009], H-222 111009, OSMW-9S 111009, OSMW-9D 111009.

III. Calibrations

Calibration data were evaluated using the validation and USEPA Method 8260B criteria. The initial calibration and calibration verifications met the validation and USEPA Method 8260B criteria.

IV. GC/MS instrument check

The GC/MS instrument checks met USEPA Method 8260B criteria.

V. Surrogate recoveries

Surrogates were evaluated using the laboratory control limits during the validation process. Surrogate recoveries were within the laboratory control limits.

VI. MS/MSD analysis

The laboratory used spikes containing the complete target analyte list to generate the MS/MSD data. The MS/MSD results were within the validation criteria.

VII. LCS analysis

The laboratory used spikes containing the complete target analyte list to generate the LCS data.

The following non-detected result was qualified as approximate (UJ) due to a minor accuracy excursion:

- The result for chloroethane in samples ADW-11S 111109 [GM-11S 111109], AF-3S 111109, GM-3S 111109, GM-7S 111109, GM-1 111109, GM-10S 111109, GM-11S 111109.

VIII. Internal standards performance

Internal standard recoveries and retention time consistency were evaluated during the validation process. Internal standards were within the validation control limits.

IX. Field duplicates

The field duplicate results were within the validation control limits.

X. Target analyte quantitation, identification and QLs

Samples were reported using dilution analyses due to elevated concentrations of target analytes. Dilutions were performed for VOC samples due to high concentrations of target analytes. If two analyses were reported by the laboratory, the analytes with concentrations that were greater than the upper calibration limit were reported from the dilution analysis and the concentrations for the remaining analytes were reported from the undiluted analysis.

The laboratory applied the qualifier "J" when the analyte concentration was greater than the MDL but less than the QL. This qualifier has been retained during the validation process to indicate that the result is considered to be approximate.

DATA USABILITY

This section evaluates data usability for these aqueous samples, trip blanks, equipment blanks, and field duplicates based on QA/QC criteria established by USEPA Methods as listed in Table 1 and presented above. Minor deficiencies in the data generation process resulted in sample data being characterized as approximate or non-detected.

A discussion of the data quality follows:

Precision: Data were not rejected for precision excursions.

Sensitivity: Dilutions were performed for VOC analysis, which resulted in elevated QLs reported for this project.

Accuracy: Data were not rejected due to accuracy excursions.

Representativeness: Data were not rejected for representativeness excursions.

Comparability: Standardized analytical methods, QLs, reference materials, and data deliverables were used throughout the data generation process for this project.

Completeness: Overall data usability with respect to completeness is 100 percent for the VOC data. Therefore, the VOC data were identified as usable for qualitative and quantitative purposes.

Table 2. Cross Reference List

Laboratory	Date Collected	Lab ID	Client ID	MATRIX	Analysis Requested
TestAmerica Buffalo	11/6/09	RSK0444-01	OSMW-12P 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-02	OSMW-12S 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-03	OSMW-12D 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-04	OSMW-12DD 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-05	OSMW-11P 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-06	OSMW-11S 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-07	OSMW-11D 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-08	OSMW-11DD 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-09	OSMW-13P 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-10	OSMW-13S 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-11	OSMW-13D 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-12	OSMW-13DD 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-13	EB-1 110609	Aqueous	VOCs
TestAmerica Buffalo	11/6/09	RSK0444-14	TB 110609	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-01	OSMW-10S 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-02	OSMW-10P 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-03	OSMW-10D 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-04	PMW-3P 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-05	PMW-3S 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-06	PMW-3D 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-07	TMW-2P 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-08	PMW-2D 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-09	PMW-4D 111009, MS/MSD	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-12	ADW-4D 111009 [PMW-4D 111009]	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-13	GM-9S 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-14	GM-3D 111009, MS/MSD	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-17	ADW-3D 111009 [GM-3D 111009]	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-18	EB-1 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-19	H-222 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-20	OSMW-9S 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-21	OSMW-9D 111009	Aqueous	VOCs
TestAmerica Buffalo	11/10/09	RSK0550-22	TRIP BLANK 111009	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	*	TRIP BLANK 111109	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-01	ADW-11S 111109 [GM-11S 111109]	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-02	EB-1 111109	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-03	AF-2S 111109	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-04	AF-3S 111109	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-05	AF-4S 111109	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-06	GM-3S 111109	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-07	GM-7S 111109	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-08	GM-1 111109	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-09	GM-10S 111109	Aqueous	VOCs
TestAmerica Buffalo	11/11/09	RSK0604-10	GM-11S 111109	Aqueous	VOCs

Note:
VOCs indicate volatile organic compounds.
TB indicates trip blank.
MS/MSD indicates matrix spike/matrix spike duplicate.
* Indicates that the trip blank was not received at the laboratory.
The location in brackets indicates the field duplicate sampling location.
TestAmerica Buffalo indicates TestAmerica of Amherst, New York.

Table 3. O'Brien & Gere Data validation approach Using USEPA National Functional Guidelines	
General Validation Approach	For certain parameters, USEPA guidance for data validation indicates that professional judgment is to be utilized to identify the appropriate validation action. In these situations, the validation approach taken by O'Brien & Gere is a conservative one; qualifiers are applied to sample data to indicate both major and minor excursions. In this way, data associated with any type of excursion are identified to the data user. Major excursions will result in data being rejected, indicating that the data are considered unusable for either quantitative or qualitative purposes. Minor excursions will result in sample data being qualified as approximate that are otherwise usable for quantitative or qualitative purposes.
	Excursions are subdivided into excursions that are within the laboratory's control and those that are out of the laboratory's control. Excursions involving laboratory control sample recovery, calibration response, method blank excursions, low or high spike recovery due to inaccurate spiking solutions or poor instrument response, holding times, interpretation errors, and quantitation errors are within the control of the laboratory. Excursions resulting from matrix spike recovery, serial dilution recovery, surrogate, and internal standard performance due to matrix interference from the matrix of the samples are examples of those excursions that are not within the laboratory's control if the laboratory has followed proper method control procedures, including performing appropriate cleanup techniques.
Parameter Type	**Applying Data Validation Qualifiers Approach***
Sample collection information- Cooler Temperature	Results for samples submitted for organic and inorganic analyses impacted by cooler temperatures of greater than 10°C are qualified as approximate (UJ, J).
Sample collection information- VOC Headspace	Results for sample containers submitted for VOC analysis that contain headspace are noted in the report.*
Sample collection information- Percent Solids	Results for samples submitted for organic and inorganic analyses that are impacted by percent solids of 50 percent or less are qualified as approximate (UJ, J).
Calibration Data- VOCs by USEPA Method 8260B	VOC target analytes are evaluated using the criteria of 15 percent relative standard deviation (%RSD) or correlation coefficient criteria of 0.990 for initial calibration curves. Calibration verifications are evaluated using a criterion of less than or equal to 20 percent difference (%D) for continuing calibration check compounds and a %D of less than or equal to 50 for the remaining target analytes. Initial calibrations and calibration verifications are also evaluated using the response factor (RF) criteria described in the method for system performance check compounds, a criterion of greater than or equal to 0.010 for ketones, and a criterion of 0.05 for the remaining target analytes. If analyzed, the initial calibration verification (second-source standard or low standard) is evaluated using a 30% recovery or the laboratory control limits.
Organic Multi-results	When two results are reported, due to re-preparation or for dilution analyses, both sets of results are evaluated during the validation process. Based on the evaluation of the associated quality control data, the results reflecting the higher quality data are reported.
General Organic MS/MSD, LCS, Duplicate Data	Laboratory established control limits are used to assess duplicate, surrogate, MS/MSD, and LCS data.
	In the case that excursions are identified in more than one quality control sample of the same matrix within one sample delivery group, samples are batched according to sample preparation or analysis date and qualified accordingly.
	If percent recoveries are less than laboratory control limits but greater than ten percent, non-detected and detected results are qualified as approximate (UJ, J) to indicate minor excursions.
	If percent recoveries are greater than laboratory control limits, detected results are qualified as approximate (J) to indicate minor excursions.
	If percent recoveries are less than ten percent, detected results are qualified as approximate (J) and non-detected results are qualified as rejected (R) to indicate major excursions.
	If RPDs for MSDs or duplicates are outside of laboratory control limits, detected results are qualified as approximate (J) to indicate minor excursions.
Organic MS/MSD Data	Qualification of organic data for MS/MSD analyses is performed only when both MS and MSD percent recoveries are outside of laboratory control limits.
	Organic data are rejected (R) to indicate major excursions in the case that both MS/MSD recoveries are less than ten percent.
Sample dilution Data	Qualification of data is not performed if MS/MSD or surrogate recoveries are outside of laboratory control limits due to sample dilution.
Organic MS/MSD and Field Duplicate Data	Qualification of data associated with MS/MSD or field duplicate excursions is limited to the un-spiked sample or the field duplicate pair, respectively.
Field Duplicate Data	Field duplicate data are evaluated against relative percent difference (RPD) criteria of less than 50 percent

	for aqueous samples and less than 100 percent for soils when results are greater than five times the QL. When sample results for field duplicate pairs are less than five times the QL, the data are evaluated using control limits of plus or minus two times the QL for soils. If RPDs for field duplicates are outside of laboratory control limits, detected and non-detected results are qualified as approximate (UJ, J) to indicate minor excursions.
Organic Blank Data	If methylene chloride, acetone or 2-butanone is detected in the sample at a concentration that is less than ten times the concentration in the associated blank, the sample result is qualified as "U".
	If other target analytes are detected in the sample at a concentration that is less than five times the concentration detected in the associated blank, the sample result is qualified as "U".
	Results greater than the MDL but less than QL and within the blank action level, are replaced with the QL and qualified as non-detected (U).
	Results greater than the QL are qualified as "U" at that concentration.
	The highest concentrations of the target analytes are used to evaluate the associated samples.
	For preparation blanks and field blanks at concentrations greater than laboratory QLs: (a) Concentration sin the associated samples of greater than the blank concentration and less than ten times the blank concentration are qualified as approximate (J). (b) Concentrations in the associated samples of greater than or equal to the MDLs but less than or equal to QLs are revised to the QL level and are qualified as non-detected (U). (c) Concentration in the associated samples of greater than the QLs and less than the blank concentration are rejected (R).
	For preparation blanks at concentrations less than the negative value of the QLs: (a) Concentrations in the associated samples of less than ten times the QLs are qualified as approximate (J). (b) Non-detected concentrations in the associated samples are qualified as approximate (UJ).
Internal Standard organic Data	Internal standard recoveries are evaluated using control limits of within 50% of the lower standard area and up to 100% of the upper standard area of the associated calibration verification standard. The results for target analytes associated with internal standard area recoveries 25% or greater but less than the lower standard area are qualified as approximate (J, UJ) to indicate minor internal standard recovery excursions. The non-detected results for target analytes associated with internal standard area recoveries less than 25% are rejected (R) to indicate major recovery excursions
* Indicates that data validation guidelines do not address this situation. Therefore, validation qualifiers are not applied to data.	
Source O'Brien & Gere	

Table 4. Laboratory QA/QC analyses definitions.

QA/QC Term	Definition
Quantitation limit	The level above which numerical results may be obtained with a specified degree of confidence; the minimum concentration of an analyte in a specific matrix that can be identified and quantified above the method detection limit and within specified limits of precision and bias during routine analytical operating conditions.
Method detection limit	The minimum concentration of an analyte that undergoes preparation similar to the environmental samples and can be reported with a stated level of confidence that the analyte concentration is greater than zero.
Instrument detection limit	The lowest concentration of a metal target analyte that, when directly inputted and processed on a specific analytical instrument, produces a signal/response that is statistically distinct from the signal/response arising from equipment "noise" alone.
Gas chromatography/mass spectrometry (GC/MS) instrument performance check	Performed to verify mass resolution, identification, and to some degree, instrument sensitivity. These criteria are not sample specific; conformance is determined using standard materials.
Calibration	Compliance requirements for satisfactory instrument calibration are established to verify that the instrument is capable of producing acceptable quantitative data. Initial calibration demonstrates that the instrument is capable of acceptable performance at the beginning of analysis and calibration verifications document satisfactory maintenance and adjustment of the instrument on a day-to-day basis.
Relative Response Factor	A measure of the relative mass spectral response of an analyte compared to its internal standard. Relative Response Factors are determined by analysis of standards and are used in the calculation of concentrations of analytes in samples.
Relative standard deviation	The standard deviation divided by the mean; a unit-free measure of variability.
Correlation coefficient	A measure of the strength of the relationship between two variables.
Relative Percent Difference	Used to compare two values; the relative percent difference is based on the mean of the two values, and is reported as an absolute value, i.e., always expressed as a positive number or zero.
Percent Difference	Used to compare two values; the percent difference indicates both the direction and the magnitude of the comparison, i.e., the percent difference may be either negative, positive, or zero.
Percent Recovery	The act of determining whether or not the methodology measures all of the target analytes contained in a sample.
Calibration blank	Consists of acids and reagent water used to prepare metal samples for analysis. This type of blank is analyzed to evaluate whether contamination is occurring during the preparation and analysis of the sample.
Method blank	A water or soil blank that undergoes the preparation procedures applied to a sample (i.e., extraction, digestion, clean-up). These samples are analyzed to examine whether sample preparation, clean-up, and analysis techniques result in sample contamination.
Field/equipment	Collected and submitted for laboratory analysis, where appropriate. Field/equipment blanks are handled in the same manner as environmental samples. Equipment/field blanks are analyzed to assess contamination introduced during field sampling procedures.
Trip blank	Consist of samples of analyte-free water that have undergone shipment from the sampling site to the laboratory in coolers with the environmental samples submitted for volatile organic compound (VOC) analysis. Trip blanks will be analyzed for VOCs to determine if contamination has taken place during sample handling and/or shipment. Trip blanks will be utilized at a frequency of one each per cooler sent to the laboratory for VOC analysis.
Internal standards performance	Compounds not found in environmental samples which are spiked into samples and quality control samples at the time of sample preparation for organic analyses. Internal standards must meet retention time and recovery criteria specified in the analytical method. Internal standards are used as the basis for quantitation of the target analytes.
Surrogate recovery	Compounds similar in nature to the target analytes but not expected to be detected in the environmental media which are spiked into environmental samples, blanks, and quality control samples prior to sample preparation for organic analyses. Surrogates are used to evaluate analytical efficiency by measuring recovery.
Laboratory control sample Matrix spike blank analyses	Standard solutions that consist of known concentrations of the target analytes spiked into laboratory analyte-free water or sand. They are prepared or purchased from a certified manufacturer from a source independent from the calibration standards to provide an independent verification of the calibration procedure. They are prepared and analyzed following the same procedures employed for environmental sample analysis to assess method accuracy independently of sample matrix effects.
Laboratory duplicate	Two or more representative portions taken from one homogeneous sample by the analyst and analyzed in the same laboratory.
Matrix	The material of which the sample is composed or the substrate containing the analyte of interest, such as drinking water, waste water, air, soil/sediment, biological material.
Matrix Spike (MS)	An aliquot of a matrix (water or soil) fortified (spiked) with known quantities of specific target analytes and subjected to the entire analytical procedure in order to indicate the appropriateness of the method for the matrix by measuring recovery.
Matrix spike duplicate (MSD)	A second aliquot of the same matrix as the matrix spike that is spiked in order to determine the precision of the method.
Retention time	The time a target analyte is retained on a GC column before elution. The identification of a target analyte is dependent on a target compound's retention time falling within the specified retention time window established for that compound.
Relative retention time	The ratio of the retention time of a compound to that of a standard.

Source O'Brien & Gere

Appendix C

Summary of Groundwater Microcosm and Geochemical Results

GROUNDWATER MICROCOSM AND GEOCHEMICAL RESULTS
GE TRANSPORTATION
EVENDALE, OHIO

Sample ID		AF - 5P	AF - 5S	AF - 7P	AF - 7S	OS-MW-1D	OS-MW-1S	OS-MW-3D	TMW-1P	TMW-1S	TMW-1D	TMW-2P	TMW-2S	TMW-2D
Parameters														
Field Parameters														
Conductivity	uS/cm	853	1004	1305	718	693	721	745	1193	749	743	1342	889	535
Dissolved Oxygen	mg/L	0.41	0.2	0.28	0.16	0.1	0.1	0.3	1.46	0.14	0.11	0.11	0.16	0.16
Eh	mV	16.7	-145	-1.5	-168	-139	-128	-106.6	49.4	-173	-464	-227	-174	-567
pH	S. U.	7.26	7.28	7.25	7.27	7.25	7.13	7.18	7.28	7.42	7.49	6.94	7.4	7.4
Temperature	Deg.C	17.77	17.57	18.48	18.28	17.31	17.6	16.85	17.18	18.24	17.23	17.75	17.69	16.98
Turbidity	NTUs	25	7	34	11	49	7	7	31	26	700	47	28	600
Ferrous Iron	mg/L	0.61	3.19	0.46	3.11	3.76	2.41	2.52	1.61	1.68	--	3.03	2.34	--
Cations/Metals														
Calcium	mg/L	67	93	100	76	77	--	110	--	--	--	--	--	--
Iron (total)	mg/L	1.4	4.3	4.1	5.5	4.9	--	2.4	--	--	--	--	--	--
Magnesium	mg/L	22	43	30	30	27	--	29	--	--	--	--	--	--
Manganese	mg/L	0.19	0.28	0.23	0.55	0.4	--	0.43	--	--	--	--	--	--
Potassium	mg/L	<5	<5	<5	<5	<5	--	<5	--	--	--	--	--	--
Sodium	mg/L	110	87	190	54	52	--	33	--	--	--	--	--	--
Anions														
Alkalinity	mg/L	240	330	230	320	290	--	360	--	--	--	--	--	--
Chloride	mg/L	140	160	290	77	85	--	50	--	--	--	--	--	--
Nitrogen, Nitrate (As N)	mg/L	1.3	<0.050	1.2	<0.050	<0.050	--	<0.050	--	--	--	--	--	--
Nitrogen, Nitrite	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	--	<0.050	--	--	--	--	--	--
Phosphorus, Dissolved	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	--	<0.050	--	--	--	--	--	--
Sulfate	mg/L	72	29	80	3.5	7.9	--	59	--	--	--	--	--	--
Sulfide	mg/L	<0.8	<0.8	<0.80	<0.8	<0.8	--	<0.8	--	--	--	--	--	--
Indicator Parameters														
TOC	mg/kg	<1	1.7	<1	1.6	1.9	--	1.6	--	--	--	--	--	--
Total dissolved solids	mg/L	130	660	850	460	450	--	520	--	--	--	--	--	--
VOCs														
Acetone	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	22.2	ND
Benzene	ug/L	ND	ND	ND	ND	ND	ND	2.75	0.38	ND	ND	0.47	0.23	7.4
Carbon disulfide	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.17	ND	ND	ND
Chloroform	ug/L	ND	ND	ND	ND	ND	ND	ND	0.31	ND	0.16	ND	ND	ND
1,1-Dichloroethane	ug/L	8	28.8	70.2	27	50	76	ND	35.8	11.8	ND	6.11	0.5	4.8
1,1-Dichloroethene	ug/L	5	4.5	50.5	6.5	ND	ND	ND	18.3	ND	ND	ND	ND	ND
cis-1,2-Dichloroethene	ug/L	34.2	207	24.8	1170	814	1760	570	28.6	505	2.82	7.4	0.6	370
trans-1,2-Dichloroethene	ug/L	ND	6.4	ND	53.5	ND	48	ND	2.44	8.4	0.13	0.57	0.11	114
1,1,1 - Trichloroethane	ug/L	124	12.8	816	ND	ND	ND	ND	240	ND	ND	ND	ND	ND
1,1,2 - Trichloroethane	ug/L	ND	ND	ND	ND	ND	ND	ND	0.41	ND	ND	ND	ND	ND
Methylene Chloride	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.12	ND	ND	ND
Tetrachloroethene	ug/L	ND	ND	ND	ND	ND	ND	ND	1.03	ND	ND	ND	ND	ND
Toluene	ug/L	ND	ND	ND	ND	ND	ND	ND	0.15	ND	ND		0.2	95.7
Trichloroethene	ug/L	417	138	830	ND	ND	120	602	298	91.8	0.16	0.15	0.46	166
Vinyl Chloride	ug/L	ND	116	ND	233	133	70	ND	0.29	127	0.5	13.7	0.47	7.4
Xylenes (total)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.16	ND
Dissolved Gas														
H_2	nM	9	0.9	0.8	<0.55	2.4	--	1.6	--	--	--	--	--	--
Methane	ug/L	3.5	4,230	71	15,490	8,460	--	500	--	--	--	--	--	--
Ethane	ug/L	<0.1	10	<0.1	22	24	--	0.5	--	--	--	--	--	--
Ethene	ug/L	<0.1	12	<0.1	64	53	--	0.1	--	--	--	--	--	--
VC	ug/L	<4.0	161	<4.0	303	192	--	<4.0	--	--	--	--	--	--
CA	ug/L	<4.0	<4.0	<4.0	<4.0	<4.0	--	<4.0	--	--	--	--	--	--
CO2	mg/L	14	25	20	26	22	--	32	--	--	--	--	--	--
Anions (by BCI)														
Chloride	mg/L	133	163	293	74	85	--	48	--	--	--	--	--	--
Bromide	mg/L	<1.5	<1.5	<1.5	<1.5	<1.5	--	<1.5	--	--	--	--	--	--
Nitrite	mg/L	<1.5	<1.5	<1.5	<1.5	<1.5	--	<1.5	--	--	--	--	--	--
Sulfate	mg/L	66	30	77	2	9	--	67	--	--	--	--	--	--
Nitrate	mg/L	5	<1.5	6	<1.5	<1.5	--	<1.5	--	--	--	--	--	--
PO4 Hatch 8048	mg/L	0.02	0.02	0.19	0.05	0.12	--	0.03	--	--	--	--	--	--
NH3-N Hatch 8155	mg/L	<0.02	0.6	0.2	0.9	2.3	--	0.1	--	--	--	--	--	--
Formate	mg/L	<1.5	<1.5	<1.5	<1.5	<1.5	--	<1.5	--	--	--	--	--	--
Acetate	mg/L	<1.6	<1.6	<1.6	<1.6	<1.6	--	<1.6	--	--	--	--	--	--
Propionate/Lactate	mg/L	<1.5	<1.5	<1.5	<1.5	<1.5	--	<1.5	--	--	--	--	--	--
Butyrate	mg/L	<1.5	<1.5	<1.5	<1.5	<1.5	--	<1.5	--	--	--	--	--	--
pH (by BCI)														
pH	S. U.	7.4	7.4	7.5	7.5	7.5	--	7.5	--	--	--	--	--	--
Bioassay Results (PLFA)														
bioassay testing (Biomass)	Cells/mL	2540	3440	12600	96700	50400	--	21800	--	--	--	--	--	--
Fimicutes (TerBrSats)	%	0	3.11	5.00	8.78	6.19	--	2.37	--	--	--	--	--	--
Proteobacteria (Monos)	%	49.67	51.51	48.11	72.56	71.10	--	56.75	--	--	--	--	--	--
Anaerobic metal reducers (BrMonos)	%	0	0	0	0.83	0.92	--	2.50	--	--	--	--	--	--
SRB/Actinomycetes (MidBrSats)	%	10.91	4.65	12.84	1.51	2.53	--	1.95	--	--	--	--	--	--
General (Nsats)	%	32.22	36.11	19.59	11.95	16.33	--	24.80	--	--	--	--	--	--
Eukaryotes (polyenoics)	%	7.19	4.62	14.46	4.39	2.96	--	11.63	--	--	--	--	--	--
Bioassay Results (VFA)														
Pyruvic	mg/L	<4	<4	<4	<4	<4	--	<4	--	--	--	--	--	--
Lactic	mg/L	<1	<1	<1	<1	<1	--	<1	--	--	--	--	--	--
Formic	mg/L	<1	<1	<1	<1	<1	--	<1	--	--	--	--	--	--
Acetic	mg/L	<1	<1	<1	<1	<1	--	<1	--	--	--	--	--	--
Propionic	mg/L	<1	<1	<1	<1	<1	--	<1	--	--	--	--	--	--
Butyric	mg/L	<1	<1	<1	<1	<1	--	<1	--	--	--	--	--	--
Bioassay Results (PCR/DHC)														
PCR		detected	detected	detected	detected	detected	--	detected	--	--	--	--	--	--
Dehalococcoides ethenogenes		negative	negative	negative	negative	positive	--	negative	--	--	--	--	--	--
Dehalobacter		negative	negative	negative	negative	negative	--	negative	--	--	--	--	--	--

Notes:

--	Not analyzed
ND	Not Detected

Table 2
Biological Parameter Results

	Location ID	AF-21D	AF-21D (DUP-3)	AF-5D	AF-7D	OS-MW-1D	OS-MW-3D	OS-MW-7D (DUP-2)	OS-MW-7D	TMW-1D	TMW-2D
	Sample Date	8/7/2008	8/7/2008	8/4/2008	8/6/2008	8/7/2008	8/7/2008	8/6/2008	8/6/2008	8/4/2008	8/6/2008
Field Parameters	**Unit**										
pH	pH units	7.06	7.06	7.09	7.15	7	7.03	7.03	7.15	6.77	6.93
Conductivity	mS/cm	0.754	0.754	1.03	0.901	0.838	0.931	0.931	0.901	0.91	1.09
Turbidity	NTU	68.2	68.2	46.9	65.7	75	33	33	65.7	41.8	52.2
Dissolved Oxygen	mg/L	0.22	0.22	0	0.18	0.28	0.39	0.39	0.18	0.09	0.34
Temperature	℃	17.7	17.7	15.9	17.1	16.7	17.6	17.6	17.1	16.7	17.1
ORP	mV	-225	-225	-208	-196	-201	-200	-200	-196	-199	-188
Indicator Parameters											
Alkalinity, as CaCO3	ug/l	320000	320000	390000	380000	310000	370000	350000	370000	380000	400000
Alkalinity, Bicarbonate (as CaCO3)	ug/l	320000	320000	390000	380000	310000	370000	350000	370000	380000	400000
Alkalinity, Carbonate (as CaCO3)	ug/l	<10000	<10000	<10000	<10000	<10000	<10000	<10000	<10000	<10000	<10000
Calcium Metal	ug/l	87000	85000	120000	130000	78000	130000	120000	120000	110000	120000
Chloride	ug/l	68000	68000	59000	59000	84000	50000	38000	38000	61000	79000
Ethane	ug/l	<410	<410	<41	<4.1	<4.1	<4.1	<4.1	<4.1	<4.1	<210
Ethylene	ug/l	<410	<410	<41	<4.1	23	<4.1	<4.1	<4.1	<4.1	<210
Iron, total	ug/l	6700	6300	4200	4900	6400	2400	6400	6300	9600	6300
Iron, dissolved	ug/l	49	230	81	550	37	5.7	200	230	970	770
Magnesium	ug/l	25000	25000	39000	36000	28000	32000	31000	30000	34000	35000
Methane	ug/l	14000	11000	540	20	3000	42	2.6	2.8	1800	1200
Nitrate	ug/l	<40	1200	<40	<100	<100	<100	<100	<100	<40	<100
Potassium	ug/l	1900	2000	1800	1500	3300	2300	1600	1700	1700	2200
Sodium	ug/l	38000	39000	30000	27000	45000	27000	19000	19000	33000	45000
Sulfate	ug/l	<2000	<5000	70000	79000	8000	97000	97000	97000	28000	28000

Appendix D

Application of Stable Isotope Data to Quantify Biodegradation

APPLICATION OF STABLE ISOTOPE DATA TO QUANTIFY BIODEGRADATION

The following information is a series of direct excerpts from Hunkeler et al., (2008) to provide a basis for the calculations used in estimation of biodegradation rates from compound specific isotope analysis (CSIA) results. For a complete description and derivation of equations, the reader is referred to Section 4.0 and 7.0 of Hunkeler et al., (2008).

Application of the Rayleigh Equation - Overview

In the course of many biochemical and abiotic reactions, molecules containing the lighter isotopes exclusively (i.e. ^{12}C) tend to react more rapidly compared to molecules containing the heavy stable isotope (i.e. ^{13}C). As the reaction proceeds, the ratio of stable isotopes in the material that remains behind, in the material that has not gone through the reaction, will therefore change. The more the reaction proceeds the more pronounced the isotope shift in the ratio of ^{13}C to ^{12}C will be. This change in the ratio of stable isotopes is called stable isotope fractionation and can be expressed as the stable isotope fractionation factor alpha (α) as described in Equation 4.1:

$$\alpha = R_a/R_b = (1000 + \delta^{13}C_a) / (1000 + \delta^{13}C_b) \quad \textbf{4.1}$$

where R is the stable isotope ratio ($^{13}C/^{12}C$) of the compound, and the subscripts *a* and *b* may represent a compound at time zero (t_0) and at a later point (t) in a reaction; or a compound in a source zone, versus a down gradient well. For many organic contaminants, stable isotope fractionation during biotic and abiotic degradation can also often be quantitatively described by the Rayleigh equation (Equation 4.2):

$$R = R_0 f^{(\alpha-1)} \quad \textbf{4.2}$$

where R is the stable isotope ratio ($^{13}C/^{12}C$) of the compound at time t, R_0 is the initial isotope value of the compound and f is the ratio (C/C_0) of the concentrations of the compound at time t and zero.

The stable isotope ratio is reported in the delta notation, where the ratio is normalized to the ratio in a standard. The delta notation is defined as $\delta = (R_{sample}/R_{reference} - 1) \times 1000$, where R_{sample} and $R_{reference}$ are the carbon isotope ratios of the aqueous sample and the respective standards. The results are reported as parts per thousand, or per mil, and shown using the symbol "‰".

Equation 4.2 can be rearranged to produce Equation 4.3:

$$f = e^{(\delta^{13}C_{groundwater} - \delta^{13}C_{source})/\varepsilon)} \quad \textbf{4.3}$$

where $\delta^{13}C_{groundwater}$ is the measure of the isotope ratio in the organic contaminant in the sample of ground water, $\delta^{13}C_{source}$ is the isotopic ratio in the un-fractionated organic contaminant before biodegradation has occurred, and epsilon (ε) is the stable isotope enrichment factor as defined in Equation 4.4:

$$\varepsilon = (\alpha - 1) * 1000 \quad \textbf{4.4}$$

The larger the fractionation during the reaction the more negative is the corresponding value of epsilon.

Evaluation of Field Isotope Data and Related Equations

The following equation is usually denoted as the Rayleigh equation and describes the evolution of the isotope ratio of the reactant as a function of the progress of the reaction (Clark and Fritz, 1997; Mariotti et al., 1981).

$$f = \frac{C_t}{C_0} = \frac{H_R + L_R}{H_{R,0} + L_{R,0}} = \frac{L_R \cdot (1+R)}{L_{R,0} \cdot (1+R_0)} \qquad \textbf{7.10}$$

where f = fraction of substrate that has not reacted at time t, C_t is the concentration of compound at time t, C_0 is initial concentration of compound, H_R is the amount of heavy isotope in reactant, $H_{R,0}$ is the initial amount of heavy isotope, L_R is the amount of the light isotope in reactant, and $L_{R,0}$ is the initial amount of light isotope.

When the uncertainty of the laboratory measurement is in the same range as the uncertainty of the isotope ratio of the reference gas, the following linearized form of Equation 7.10 is used to quantify α_{PR}:

$$\ln \frac{R}{R_0} = \ln \frac{\frac{\delta^i E}{1000} + 1}{\frac{\delta^i E_0}{1000} + 1} = (\alpha_{PR} - 1) * \ln f \qquad \textbf{7.16}$$

Under certain conditions, the degree of biodegradation or the first order rate constant for biodegradation can be quantified for the zone between the source and a monitoring point, or between two monitoring points along a flow path. By rearrangement of equation 7.16, the following equation is obtained to quantify the fraction remaining (f):

$$f = \left(\frac{R}{R_0}\right)^{1/\alpha PR - 1} = \left(\frac{\delta^i E + 1000}{\delta^i E_0 + 1000}\right)^{1000/\varepsilon PR} \qquad \textbf{7.17}$$

where $\delta^i E$ is the isotope ratio at the downgradient monitoring point, and $\delta^i E_0$ is the isotope ratio at the source or upgradient monitoring point.

The amount of biodegradation or abiotic transformation (in percent of the material originally present) is given by:

$$B = (1 - f) * 100 \qquad \textbf{7.18}$$

The CSIA data can also be used to extrapolate contaminant degradation further down the flow path. The first order rate constant for the contaminant removal can be estimated by combining Equation 7.10 with the equation describing first-order degradation of a substance:

$$f = \frac{C}{C_0} = \exp(-\lambda_t * T) \qquad \textbf{7.20}$$

where T is the average travel time of the compounds of interest between source and monitoring point or between two monitoring points along a flow line. For retarded compounds, the travel time is given by $T = R_T * T_W$ where R_T is the retardation factor and T_W is the average travel time of water, λ_t= the first order rate constant for the reduction in concentration due to biodegradation or abiotic transformation.

Solving Equation 7.20 for λ_t, and then substituting Equation 7.17 for *f*, produces Equation 7.21:

$$\lambda_t = - \frac{\frac{1}{\varepsilon_{PR}} * \ln \frac{R}{R_o}}{T} = - \frac{\frac{1000}{\varepsilon_{PR}} * \ln \frac{\delta^i E + 1000}{\delta^i E_o + 1000}}{T} \qquad \textbf{7.21}$$

The calculated rate constant represents the rate of removal from biodegradation or abiotic transformation. The rate of removal is distinct from the bulk attenuation rate *k* that is calculated by plotting the natural logarithm of the concentrations against the time of travel along the flow path (Newell et al., 2002). The bulk attenuation rate also includes the effect of dilution through dispersion on the concentration in addition to the effect of removal.

An example solution for Equation 7.21 using data from the Site to estimate the biodegradation rates (λ_t) presented in Table 7 is as follows:

Using the $\delta^{13}C$ values for TCE for AF-7P (-25‰) and PMW-3P (-20.6‰), and assuming that the isotopic value measured at AF-7P is representative of the upgradient release/source location (i.e., $\delta^{13}C_o$), then:

$\delta^i E$ = carbon isotope ratio $\delta^{13}C$ at downgradient point (PMW-3P) = -20.6‰
$\delta^i E_o$= carbon isotope ratio $\delta^{13}C_o$ at the source or upgradient point (AF-7P)[1] = -25‰

ε_{PR} = isotope enrichment factor; using an average (ε_{AVG}) = -12.0

T = average travel time (assuming no retardation or R=1) between AF-7P and PMW-3P = L/v = 59 days, where:

L = distance between AF-7P and PMW-3P = 252 feet
v = average groundwater velocity = 4.3 feet/day

$$\lambda_{AVG} = - \frac{\frac{1000}{\varepsilon_{PR}} * \ln \frac{\delta^i E + 1000}{\delta^i E_o + 1000}}{T}$$

$$\lambda_{AVG} = - \frac{1000}{(-12.0)} * \frac{\ln [(-20.6‰ + 1000)/(-25‰ + 1000)]}{59 \text{ days}}$$

$$\lambda_{AVG} = \frac{83.3 * \ln [979.4 / 975]}{59 \text{ days}} = 0.375/59 = 0.0064 \text{ day}^{-1}$$

[1] The alternate approach is to use the mean value of -29‰ for undegraded TCE ($\delta^{13}C_{source}$ or $\delta^{13}C_o$), as also presented in Table 7.

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